WAVES, RAYS AND RADIUM
AN HISTORICAL PERSPECTIVE ON THE FOUNDERS

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Submitted to the faculty of the University Graduate School
in partial fulfillment of the requirements
for the degree
Masters of Liberal Studies
in the College of Liberal Arts and Sciences
Indiana University South Bend
December 2002

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Accepted by the Graduate Faculty of Indiana University South Bend in partial fulfillment of the requirements for the degree of Master of Liberal Studies.

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December 3, 2002
Date of Oral Examination

ACKNOWLEDGMENTS

I am grateful to Professor Patrick J. Furlong and James H. Howard, for their assistance with my project. A special note of thanks goes to Professor Teresa Dobrzykowski, for diligently making suggestions and adding words of encouragement with each section of the project, until its completion.

LIST OF ILLUSTRATIONS

Over a hundred years ago these five scientists initiated a chain of events that changed our lives and our understanding of our bodies. Michael Faraday received very

little formal education and yet he developed the most fundamental changes in the basic theories of physics. In 1838, Faraday discovered conductors and he tried producing currents in wires within vacuum tubes (May 115). Because of Faraday's work, Wilhelm Conrad Roentgen was able to discover x-rays. Faraday also discovered that electricity could be produced from a magnet. This became the basis of the modern day magnetic resonance signal detection. Faraday noted that in order for the magnetic field to be sustained, it had to be pulsed (Woodard, Freimarck 2). He made many significant contributions that inspired other scientists, such as Antoine Henri Becquerel, to do further research.

The discovery of radioactivity was the beginning of nuclear physics. In 1895 Roentgen discovered x-rays (Glasser 36). News traveled quickly of these rays producing skeletal parts on a photographic plate. Physicists everywhere rushed to investigate these mysterious rays. Roentgen actually discovered x-rays by chance while working with evacuated glass tubes. He was surprised to see a glow on the other side of the room when he charged the tube. It became the most important invention of the 19th century (Greene 323).

Antoine Henri Becquerel was inspired by both Faraday and Roentgen's work. He followed up work done on magneto-optics by Faraday and he developed a standard for electrical current strength (McMurray 133). Intrigued by Roentgen's x-rays, he searched for a connection between the x-rays and phosphorescence. In 1896, he processed some photographic plates he had stored in a drawer with uranium salts and discovered the salts fogged the plates with rays they had naturally emitted (McMurray 134). This was without the transfer of energy from the sun, because Becquerel had stored them on a cloudy day for future experimenting. He had discovered natural radiation. He researched the rays further, but limited his studies to the uranium salts.

Marie Curie had been a graduate student of Becquerel's (McMurray 133). She needed an interesting topic for her doctorate thesis and believed Becquerel's rays would be a perfect area of study. There were few people researching his uranium rays at the time because so many people were in awe of x-rays. While researching uranium, Marie and Pierre Curie realized that pitchblende, an ore of uranium, was three hundred times stronger than pure uranium. They searched for the powerful radioactive material within pitchblende. In 1898, they discovered two radioactive elements, radium and polonium (Hallock 17). It took Marie four years to separate radium from the wastes left behind from refining uranium from pitchblende (Curie 175). After Pierre's death, Marie isolated metallic radium through electrolysis and received a second Nobel Prize in 1911 (Curie 278).

The Curie's daughter Irene, and her husband Frederic Joliot, discovered artificial radioactivity in 1934 (McGrayne 136). This meant that scientists would be able to create and control new radioactive materials. The Joliot-Curie's shot aluminum with helium nuclei and created radioactive phosphorus.

This led to nuclear energy. It also led to the creation of the atomic bomb launched in 1945. Today, x-rays and radioactivity are used in numerous fields including, medicine biology, archaeology, forensic anthropology, and industry.

Michael Faraday was born September 22,1791 in Newington Butts, London (Gunston 21). His father, James Faraday, was a blacksmith. His parents were hard workers but poor and uneducated. Michael was the third out of four in the family (24). In 1801, at the age of nine his father became ill, forcing the family to seek welfare. Faraday was given two pieces of bread to eat each day (25).

His older brother Robert became a blacksmith's apprentice to help support the family. Eventually his father became an invalid and Faraday had to learn a trade. Education was emphasized only in the homes of the rich. At the age of thirteen he became an errand boy at a book/newspaper shop. In the 1800s a newspaper was a luxury few people could afford (May 8). Only a small number of books were published each year, they were expensive and few people purchased them. Those who did, read them over and over, eventually needing them rebound.

Faraday worked as an unpaid apprentice. He worked for George Riebau whose shop was right around the corner from his home (Gunston 27). Riebau loaned newspapers to a list of customers for a small fee and Faraday delivered them from house to house. It proved to be an excellent arrangement for Faraday because he was allowed to read the books he had to bind and deliver. Author David Gunston quoted Faraday in his own words stating:

> Whilst an apprentice I loved to read the scientific books which were under my hands. It was in those books, in the hours after work that I found the beginning of my philosophy. There were two that especially helped me, The Encyclopedia Britannica, from which I gained my first notions of electricity, and Marcet's Conversations in Chemistry, which gave me my foundation in

> science. Do not suppose that I was a very deep thinker, or was marked a precocious person. I was a very lively, imaginative person, and could believe in the Arabian nights as easily as in the Encyclopedia; but facts were important to me, and saved me. I could trust a fact, and always cross-examined an assertion. So when I questioned Marcet's book by such little experiments as I could understand them. I felt that I had got hold of an anchor in chemical knowledge, and clung fast to it (28-29).

George Riebau proved to be a kindhearted man and allowed Faraday to read and encouraged his interests. Faraday lived and worked at Riebau's house for seven years (30). There was also an artist that rented from George Riebau by the name of J.J. Masquerier (30). J.J. Masquerier fled from France because peace had not come to Europe even though the French Revolution ended in 1802 (May 20). Faraday learned to draw by taking lessons from Masquerier in exchange for cleaning his room. This made it possible for Faraday to include rough sketches with his scientific research.

In 1810 Faraday's father died at the age of forty-nine (Gunston 30). His mother was forced to take in renters and his brother became the breadwinner of the family by blacksmithing (30). Faraday was now in his fifth year of apprenticeship. One day he noticed posters along the streets advertising scientific lectures to be held by Mr. J. Tatum at his house on Dorset Street (30). There was an entrance fee of one shilling for each lecture, and his brother Robert provided it each time he attended (30). Tatum's lectures fascinated Faraday. In the course of eighteen months he went to Mr. Tatum's house twelve times (May 20). Tatum's lectures included such topics as: electricity, mechanics, chemistry and magnetism (Gunston 30). Faraday took detailed notes and actually bound them into books that are still in existence. It was at these lectures that Faraday met and became friends with three men of the more privileged classes. These were Abott, a confidential clerk, Phillips, a young chemist and Huxtable, a medical student (31). Abott became a life long friend to Faraday and helped him develop good grammar and composition (32).

In 1812, a customer by the name of Mr. Dance came into the book binding shop (32). He was a member of the Royal Institution of Great Britain and he gave Faraday tickets to four chemistry lectures. These lectures were to be held by a brilliant eminent professor in the world of science known as Humphrey Davy. In 1807, Davy had discovered potassium and sodium (34). Faraday carefully took notes on all four lectures given by Davy. He bounded these 386 pages of lecture notes in leather (34). After the lectures Faraday was determined to enter the field of science.

His apprenticeship ended in 1812 and he started work as a bookbinder for Mr. De La Roche (35). De La Roche was not as kind and good-natured as Riebau had been. Faraday wanted to be a scientist. He first wrote to Sir Joseph Banks, then president of the Royal Society to ask if there was a position he could apply for; but he never received any reply (May 36). He continued working for Monsieur De La Roche, but at the encouragement of Riebau he mailed a letter with his bonded notes of Davy's lectures to Humphry Davy, the head of the laboratory (37).

On Christmas Eve 1812, he received a reply back saying he should come to the Royal Institution for an interview. Davy advised Faraday to remain a bookbinder and he would give him some business rewriting his notes. However, Davy's assistant, William Payne, was dismissed for hitting a staff member (Gunston 38). Sir Davy then offered the position to Faraday at twenty-five shillings a week, and two attic rooms to live in (May 44). De La Roche had no children to leave his shop to, so he offered Faraday his shop and home, if he would continue to work for him (45). Faraday chose to leave his bookbinding job and take the position appointed to him by the Royal Society on March 1, 1813 (Gunston 39). He remained living at the institution for nearly fifty years (39).

In his first year at the Institution Davy asked him to travel to Europe with him. He was asked to be a temporary valet for Davy and his wife (May 51). On his voyage to Europe he met: Andre Ampere, the great mathematician and discoverer in the field of electromagnetism, Joseph Gay-Lussac, a great physicist and chemist, who discovered that water is composed of hydrogen and oxygen, Alexander Humboldt, explorer and naturalist and Georges Cuvier, a naturalist and anatomist who worked on the classification of animals (Gunston 44).

Faraday was determined to widen his education while visiting Europe. While in Italy, Faraday analyzed hydroburet, an inflammable gas that is known today as methane (47). Davy then announced he isolated a new element known as iodine (May 53). The French scientist, Joseph Gay-Lussac claimed he did, but his calculations were not right (55). This made Napoleon very angry with Humphry Davy. Napoleon was defeated in the spring of 1814 and on April 12 had been forced to give up his throne (66). So Faraday decided to continue to travel with Davy and not return home, as he had originally planned. However, on March 1, 1815, Napoleon returned to French soil and war resumed (66). Davy decided it would be wise to return home.

When Faraday returned home he had no job because he had to resign in order to travel and he was replaced. Davy spoke on his behalf and the Royal Institution gave him the position of Assistant of the Laboratory and Mineralogical Collection and Superintendent of the Apparatus (Gunston 50). This job increased his pay to thirty shillings a week (50). He gave his mother more money to pay for his younger sister's attendance at boarding school.

Davy and Faraday continued experimenting and created a miner's lamp that saved lives all over the world. This lamp had a wire gauze covering that would not ignite such gases as methane (51). Faraday's progress from the years 1815 to 1820 was steady. He had no desire to seek fame or fortune as a scientist. His first published contribution was in 1816, at the age of twenty-four (52). It was a brief analysis of the native caustic lime of Tuscany and printed in the *Quarterly Journal of Science* (52). In 1818, he took elocution lessons at a half a guinea a lesson (54). He wanted to improve his vocabulary because he was giving more lectures at the institution. He had taken notes during his lessons and bound them into a 130-page book (54). Professor Thomas Brande, who acted as head of the laboratory. while Davy was away, asked Faraday to be the editor of the *Quarterly Journal of Science* (May 70). Faraday published six papers in the journal the following year and eleven in 1818 (70).

He was always fascinated by the subject of electromagnetism and wanted to pursue this subject in his lab experiments. Such men as Charles Augustin Coulomb in France and Henry Cavendish in England believed there was a connection between electrical and magnetic forces; but no one had done any experiments to confirm it. In 1820 a Danish scientist, Professor Hans Christian Oersted performed the first experiments in electromagnetism (Gunston 57). He had to prove a link between magnetism and electricity. Andre Ampere had discovered the basic laws of magnetism and electricity and expanded on Oersted's work. Before Faraday began experiments in magnetism he spent a whole summer reading what was known on the subject. He wrote up notes on all his research and titled it, *A Historical Sketch of Electromagnetism* (60). It was published in three parts, the first appearing in September 1821 (60).

In 1818, he began working with James Stodart, a surgical instrument maker, to perfect steel alloys so they would be rust free (76). He discovered an alloy called metal of alumine, now known as aluminum. Some of his samples of alloys of steel were found to be stainless steel (77). As a result, Faraday produced some very fine steel razors.

Robert Faraday delivered cylinders of illuminating gas. The days of the candle and oil lamp were coming to an end. Cylinders of gas were heavy and had to be delivered from house to house. Robert told Michael that none of the cylinders were ever totally emptied. So Faraday studied the contents and found it contained hydrogen and twelve parts of carbon (May 92). He called it bicarburet of hydrogen, which is commonly known as benzene (92). It is mixed with toluene and chiefly used as a motor fuel. It is also the base for all dyes and perfumes. Famous artists such as JMW Turner came to Faraday for advice about pigments (121). He helped them develop new colors and paints that would last.

On September 3rd and 4th 1821, he had proven not only that a magnetic force was set up when a current passed through a conductor wire, but it could rotate the wire in continuous circles (Gunston 61).

Because of his many achievements, Faraday's friends put his name up for election into the Royal Society, in Jan. 1824. There was only one negative ballot entered against him, that of Humphry Davy (May 88). He appeared to be jealous of Faraday's success at times. However, in 1825 Davy proposed that Faraday be made director of the laboratory in honor of his valuable service to the institution (95). In 1826, regular Friday night lectures for the public were held in the theater of the institution (95). The admission fees and donations from the wealthy men kept the institution going. For nineteen years Faraday participated in Christmas lectures for children (97). His lectures were very popular. Queen Victoria came to hear Faraday in 1855, which attracted yet more financial wealth to the institution (121).

In 1828 he worked to produce optical glass, but received little support (Gunston 82). So he produced prisms that helped him realize the effect of magnetism upon polarized light. He used some of the glass in his experiments that led to what he termed diamagnetism (83). Faraday always returned to experiments and research in electricity and magnetism (May 97).

On August 29,1831, he made his most important discovery in the field of electricity (Gunston 61). He knew if an electric current in a wire could produce a magnetic field; then a magnet near a conducting wire should produce an electric current. Using a battery he was able to get a reaction on a magnetic needle. One coil of wire was attached to a galvanometer and another to the battery. He was only able to get the needle to positively deflect when the magnetic field was changing, either switching on or off (70). He had produced electricity through magnetism for the first time.

In October of the same year he tried another experiment. Using an upright solenoid he connected wire to a galvanometer. Using no battery at all, he alternately plunged into and out of the center of the solenoid an ordinary bar magnet (71). The galvanometer flickered each time the magnet moved into or away from the coil (71). This was a greater achievement because he produced electricity from magnetism without a battery. He did not publish the results of this experiment until November 1831(May 111). Faraday made it possible to go from steam power to electric power. He also discovered the principle of the transformer by varying the current in one coil; he produced brief currents in the other coil. His goals were always set on experimenting and discovering; he had little desire to invent and carry his discovery to its fullest possibility.

Until the 1830s, scientists had thought of electricity as being of several different kinds. Faraday was able to show that they are really all the same. In 1833, he announced that electricity existed in five forms: voltaic/chemical, animal/eels, frictional, thermal and magnetic (Gunston 88). In January 1836, Faraday discovered conductors (May 114). To be able to observe sparks closely, he tried producing them in vacuums in 1838 (115). Sir William Crookes, an English scientist later became famous for his work with vacuum tubes. Because of Faraday's pioneer work, the German physicist Wilhelm Roentgen was able to go further with vacuum tubes and discover x-rays.

In the late 1830s improvements in dynamos had been developed. E.M. Clarke designed the first improved electric dynamo in 1835 (120). The generators we have today are directly descended from his machine based on Faraday's principles (Michael 2). The first application of his invention was a dynamo driven by waterpower that lit the streets of the town of Godalming in Surrey, England in 1881 (Gunston 122). Faraday used one of the improved electric dynamos to do exactly the same things that other experimenters did with electricity from a battery. With the electric dynamo he could separate liquids into different elements or parts, now known as electrolysis (May 116). Electrolysis is used for all types of plating. It is often used for gold-plated jewelry, chromium plated car bumpers and electrolyte printing. His work on electrolysis also led to electroforming, in which metal is electro deposited on a mold and then the mold is removed (Thomas 51-52). This was the process used in the production of phonograph records and medals (52).

In 1834, he invented the voltameter to measure voltaic electricity (Gunston 91). The voltameter was the first device to ever measure voltaic electricity. On September 13, 1845, he experimented with prisms he had made and concluded that magnetic force and light were related (94). Faraday realized that all substances have some sort of magnetic condition. He believed they were either magnetic or paramagnetic (95). In 1847 and 1850 he tried placing many different gases between the poles of a strong magnet to see how they behaved (96). He found that oxygen is strongly magnetic.

Because of his contributions to the field of electricity and magnetism his name denotes quantities of electricity. The term "Faraday" is used to denote the quantity of electricity to produce certain conditions in electrolysis (90). The farad is a unit of electrical capacity (90). Faraday developed such terms as: electrode, electrolyte, anode and cathode (May 118). Faraday pointed the way to the discovery of the electron and other parts of the atom.

Faraday became a respected scientist and was called upon to testify in court many times. There were no standards for food and drugs; druggists, doctors and others were charged with malpractice (96). The University of London offered him a professorship of chemistry, but he turned it down (96). He was totally loyal to the Royal Institution. Faraday made friends with John Fuller, a member of parliament that founded a professorship of chemistry at the Royal Institution (100). Fuller appointed Faraday the first professor for life and doubled his salary (100). He cared little for money or fame, and when he was offered the presidency of the Royal Society, he turned it down (126). Queen Victoria wanted to knight him and he refused this also (126). In 1840 he suffered a break down and did not get back to recording in his notebooks until 1842 (119).

Faraday belonged to a Christian sect called the Glasites or Sandemanians (Cantor, Gooding, and James 17). Sandemanians were opposed to the accumulation of wealth (Thomas 28). It was a strict literalist belief. Faraday did not accept poverty but lived without hoarding money or accumulating luxuries. He donated a significant amount of his earnings to the church and remained devoted to his faith while pursuing science (Cantor, Gooding, and James 18). In later years after he was famous he continued to devote time to the sick and poor Sandemanians. He displayed a dislike for politics and power, which is why he turned down being knighted and other various honors. Faraday believed that Britain handed out awards for political services that were not truly earned. He remained in the Sandemanian church his whole life and served as deacon from 1832-40 and as an elder from 1840-44 and 1860-64 (18).

In later years he became an advisor to Trinity House, the organization that had charge of England's lighthouses (May 121). He helped improve their lighting. His older inventions had improved light from oil lights to electrical machinery. Besides improving the lights themselves, Faraday found ways to keep the lighthouse windows from frosting in cold weather. He was also a pioneer in ventilation, because he ventilated inner rooms of the Royal Institution and lighthouses to protect the keepers from the poisonous fumes of old oil lights in the towers (122).

Most of Faraday's significant achievements came only after he reached the age of forty (Gunston 109). He became a great writer and an even better lecturer over time. His discovery in 1831 of the electric dynamo was the forerunner to the giant generator that supplies electric power today. His discovery of the transformer allowed for the generation of an electric railway, electric currents over long distances and household uses (121). Smaller transformers were developed to create voltage for small appliances such as shavers and radios. Faraday helped modernize the world. His discoveries in electricity were not applied fully until fifty years later.

His realization that magnetism could produce electricity led to Faraday's law of magnetic induction which is the basis of magnetic resonance signal detection and the precursor to electro mechanics (Woodward, Freimarck 2). He found that when a magnetic field passed through an electrical coil at a 90-degree angle, it could induce a voltage in that coil (2). He also realized that in order to sustain the magnetic induction, the current had to be interrupted (2). His theory on the lines of force moving between electrical and magnetic properties enabled James Clerk Maxwell to formulate a mathematical theory of the propagation of electromagnetic waves (Michael 3). Maxwell was able to prove by calculation the velocity and propagation of electromagnetic waves through space with the velocity of light (3). This led to the foundation of radio communication confirmed by Heinrich Hertz in 1888, and developed further by Guglielmo Marconi (3). Interestingly, in the four hundred and fifty publications, Faraday had written there is not a single equation, because he knew no mathematics (Thomas 1). Author John Meurig Thomas stated:

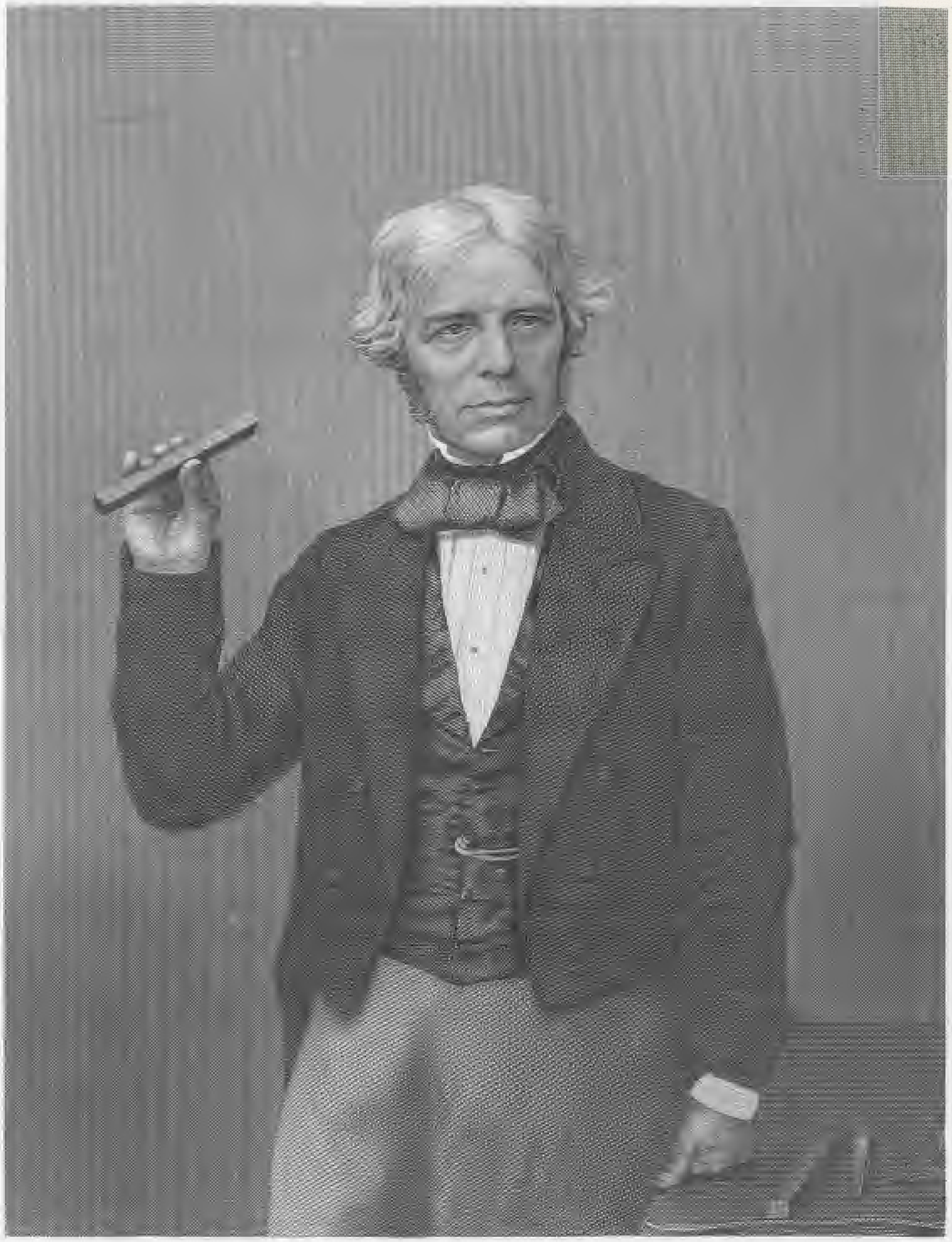
> Major conceptual advances followed when Heinrich Hertz in Karlsruhe discovered electromagnetic invisible waves, the wonderful realization dawned that visible light is no different in principle from radio waves. And when, in the fullness of time,

> the x-rays of Roentgen and the y-rays accompanying radioactive decay were discovered, the essential synonymy of all these waves were understood (69).

Faraday performed his last experiment in 1862 and it was the basis for his last lecture that same year (May 129). His last great tribute was his election in 1864 to the Royal Academy of Science of Naples in Italy (130). He had received a total of ninety- seven awards and honors at the end of his career (Gunston 86). In his lifetime he performed more than 5000 experiments (182). He ended his connection with the Royal Institution after fifty years in 1865 (Michael 3). Cantor, Gooding, and James stated:

> He summed up his attitude towards death in a letter to his close friend, the Genevan scientist Auguste De La Rive: I am, I hope, very thankful that in the withdrawal of the powers and things of this life, the good hope is left with me, which makes the contemplation of death a comfort, not a fear. Such peace is alone in the gift of God; and as it is he who gives it, why should we be afraid? His unspeakable gift in his beloved son Jesus is the ground of no doubtful hope..I am happy and content (20).

He died August 25,1867 at his home at Hampton Court (May 129). His last request was to be buried with a simple funeral with a few close friends and family present (129). He wanted a simple tombstone with no decorations (129). His inventions had a dynamic effect on subsequent technical and scientific development. He truly earned the title of the Father of Electricity (Woodard, Freimarck 2).



M. Faraday

Wilhelm Conrad Roentgen became an overnight success worldwide at the age of fifty as the discoverer of x-ray (Greene 323). He was director of the Physical Institute, and professor of physics at Wurzburg University (323). The importance of x-ray spread quickly within the medical community. Within a few months the industry of x-ray was born. Laws and trade had been greatly affected by x-rays. People were concerned about being looked at through their clothes. In 1896, a company in London advertised x-ray proof underwear (Glasser 82). Legislature in New Jersey prohibited the use of x-rays in opera glasses (82). The F.J. Pearson Manufacturing Company of St. Louis sold a portable x-ray machine complete with: a case, coil, condenser, two tubes and a battery for fifteen dollars (88). Roentgen never allowed restrictions on his discovery. He did not seek any patents, contracts or licenses (82). Thomas Edison did not share the same views as Roentgen concerning the commercial exploitation of science. He stated:

> Professor Roentgen probably does not draw one-dollar profit from his discovery. He belongs to those pure scientists who study for pleasure and love to delve into the secrets of nature. After they have discovered something wonderful, someone else must come to look at it from the commercial point of view. This will also be the case with Roentgen's discovery. One must see how to use it and how to profit by it financially (83).

Roentgen was angered by some of the applications of his rays. Several people started having skin reactions, similar to sunburn, while using x-rays. One of the first recorded incidents was at Bloomingdale Brothers in New York. A Mr. Hawks, a demonstrator of x-rays suffered a severe reaction (89). He ran the x-ray unit for two to three hours a day (89). This article appeared in the Electrical Engineer:

> To add to the many attractions of their large establishment, Bloomingdale Brothers have recently opened an x-ray exhibition. A few words as to the details of this apparatus may be of interest. The coil is an eight-inch splitdorf with the make and break circuit mounted on the shaft of a motor. I am able to make a clear photograph of the hand with a 20 to 30 seconds of exposure and a picture of the ribs in about 10 to 15 minutes. A very essential thing in running tubes to the maximum effect is to keep the air around them dry. All who are interested in the x-ray should call at Bloomingdale Brothers and see the apparatus in operation (90).

Roentgen was extremely disappointed when he learned that people were experiencing negative effects from radiation (90). Hawks experienced burns. impaired vision and hair loss (90). Many people were experimenting with the x-rays, the year after their discovery there were a thousand forty four papers and forty-nine books published about x-rays (Quinn 140).

Roentgen's early life certainly did not predict his future as a world-renowned physicist. He was the only child of Friedrich Conrad Roentgen and Charlotte Constanze Frowein (Glasser 4). He was born on March 27, 1845 in Lennep, Germany (3). He grew up in Apeldoorn, Holland (6). He went to live with a family friend, and well-known chemist named J.W. Gunning so he could attend the Utrecht Technical School in 1862 (6). He was an average student that loved to create mechanical gadgets (7). He was expelled from technical school when he confessed to doing a caricature of his teacher (7). In reality, Roentgen was poor at drawing and took the blame for a friend (7).

In the Roentgen family there were few scholars, one attorney and two surgeons (7). His family belonged to the wealthy upper class that was respected in business (Grey 8). His grandfather had been mayor of Lennep (9). In 1865, he began attending the University of Utrecht (22). They could not grant him a degree or register him as a regular student because he had not passed an entrance exam at the Utrecht Technical School. He was listed as a student of philosophy (22). Roentgen wrote a friend:

> In order not to lose touch with science, I registered myself as an auditor at Utrecht University. There I attended lectures on physics, chemistry and zoology. In the summer of 1865, I began to consider seriously which town would be the most suitable for my later training as a machine engineer, since this career seemed to fit in best with my interests and learning. Obviously it was not Utrecht (23).

A Swiss friend of the family named Thormann informed Roentgen that the Polytechnical School in Zurich accepted students lacking credentials if they could pass the difficult entrance exams (Glasser 8). He wanted to study applied mathematics at Utrecht but he developed Phlyctaenula Keratitis or ulcers that impaired his vision in one eye and feared this would keep him from taking the exams (Grey 25). He entered the Polytechnical School in 1865 (Glasser 9). He studied several areas of mechanical engineering for three years (9). His instructors were prominent men in the engineering and science field.

He was frequently absent from school and appeared at the laboratory only when he had to (Grey 26). He often rented four horse carriages to drive around Zurich for fun (28). While at college his nickname was Apeldoorn, after his hometown (29). He received a diploma as a mechanical engineer from the

Polytechnical School in 1868 (31). He ultimately studied physics. He had previously taken only one course in physics given by the father of thermodynamics, Clausius (Glasser 10). He never had a course in experimental physics (10). He wanted to acquire a doctorate degree, but was not listed as a regular student at the University. He read the rules and the University did not state that a thesis could not be written to try for a doctorate, so he began composing a thesis on gases (Grey 34).

He worked with Professor Kundt who encouraged him to pursue physics. Roentgen's thesis was deemed efficiently good and accepted by the University of Zurich (37). He graduated with a doctorate in 1869 and was officially a scientist (37). He went on to work as Kundt's laboratory assistant (Glasser 14). In 1870, when Kundt was called to the chair of Physics at the Wurzburg University, he took Roentgen with him (15). On January 19,1872, he married Anna Bertha Ludwig after a three year engagement (15). They were continuously concerned about money and seldom had enough to live on (Grey 49). Roentgen had counted on his father to help them by sending money regularly, but his father disapproved of the marriage and refused them any help (49).

Many of the instructors did not believe Roentgen was talented or bright and they let him know it (46). However, Kundt believed in him and noticed his excellent work habits in the laboratory. Kundt asked that Roentgen be given the rank of *Privat dozent*, the lowest ranking teaching position (47). It would be a beginning of a career in teaching for him. They refused to give him a position because he had no diploma (47). Kundt was determined and looked for other schools that might give Roentgen a teaching position. They both made a move to a newly founded school, The Imperial German University in Strasbourg (48). The Germans had just won this region in the Franco-Prussian War, Roentgen stated:

> In the aftermath of the victorious Franco-Prussian war, life was freer and many an ancient tradition had been cast aside. Kundt at once realized that here was a favorable opportunity for my graduation- a realization for which I can never be sufficiently grateful to him. Many another in his position would no longer have bothered himself about the future of his assistant, the less so after his first attempt to nominate me had been turned down. This time, in order to make double sure, he first obtained the support of the two influential colleagues, and only then put his suggestion before the faculty. And: lo and behold. What Wurzburg had vetoed but a few months previously, Strasbourg now accepted by a large majority. I finally received my diploma, and so began my academic career. A man must always have luck in life if he is to get anywhere (48).

In April 1872, Kundt and Roentgen made a move to Kaiser-Wilhelms University in Strassburg (Glasser 19). After working hard for two years Roentgen was finally appointed *Privat dozent* or unpaid lecturer, on March 13, 1874 (20). He constructed a number of basic devices to demonstrate physical phenomena (20). He found he had an equal interest in physics and teaching. Kundt helped him once again, and he acquired a full professorship in physics and mathematics at the Agricultural Academy in Hohenheim, Wurttemberg in 1875 (20). Roentgen and his wife were not happy in Hohenheim and did not care for the people (Grey 50). They had to break all the ties they had at Strassburg and they missed Roentgen's parents and the Kundt's

(Glasser 20). The laboratories in Hohenheim were lacking and he was unable to do creditable research (20).

He returned to Strassburg 11/2 years later as an associate professor in theoretical physics (20). He studied various fields of physics for three years (Grey 51). He wrote fifteen papers on his research (51). His papers varied topic wise to include: the heat of gases, soldering platinum plated glasses, and a telephonic alarm in 1878, which demonstrated his technical skill (51). He also wrote in collaboration with Kundt four other papers on their successful measurement of the electromagnetic rotation of the plane of polarization (Glasser 20). They had proven the existence of this rotation and measured it quantitatively, a phenomenon their great predecessor Faraday, had attempted to demonstrate (21).

Roentgen was greatly interested in crystals. He believed they were the key to natural laws (21). He discovered x-rays forty years later by studying crystals (21). He researched the conduction of heat in crystals and extended his studies to include actinoelectric and piezoelectric properties while still at Strassburg (21). Roentgen was very skillful in his experimental investigations and was careful to carry out rigidly controlled tests before presenting his findings in a brief but exact manner (21). Scientists began to notice his work and in 1879, he was offered the chair of physics at the Hessian University at Giessen (21-22). Many prominent physicists had recommended him for the post. These included such men as "Von Helmholtz, Meyer, and Kerchoff "(Grey 52). Roentgen was only thirty-four years old when he held the title of

Professor of Physics and Director of the Physical Institute of the Ludwig University in Geissen (52). He was disappointed that the lab rooms were within their home on the Frankfurter Strasse (52). They lived upstairs and the labs were downstairs (52).

The Roentgen's quickly made friends. Theodor Boveri and his wife Margaret and their daughter were their closet friends (53). While at Geissen, Roentgen investigated the so-called Kerr effect, before it was officially discovered (Glasser 22). Many of his findings go unchallenged today because of his extreme accuracy of measurement (23).

After seven years of marriage the Roentgen's were still unable to have children, so they agreed to raise Bertha's six-year-old niece, Josephine Bertha Ludwig (23). Her father agreed to let the Roentgens raise her as their daughter (Grey 53). They legally adopted her when she turned twenty-one years old (Glasser 23). Roentgen was a very strict parent and he believed his wife allowed the child too much freedom (Grey 54).

Roentgen became financially independent in 1888 (Glasser 23). He had acquired a reputation when he had proven that "magnetic effects are produced in a dielectric, such as a glass plate, when it is moved between two electrically charged condenser plates" (23). This was based upon the theory of the Faraday-Maxwell electromagnetic hypothesis. He ideally coordinated his ability as an experimenter and theorist (24). Years later, he explained to Margaret Boveri the distinction between experimental and theoretical physics. He stated:

> To my view there are two methods of research, the apparatus and the calculation. Whoever prefers the first method is an

> experimenter, otherwise, he is a mathematical physicist. Both of them set up theories and hypotheses.. (24).

In 1886 the University of Jena offered him its chair of physics, and two years later the University of Utrecht asked him to come there because of his publications (25). The very school that had rejected him as a regular student; now told him he had exceptional knowledge and intellect with original ideas (25). He replied:

> To move into entirely new surroundings would require too much of my time, which I had rather devote to scientific investigations (25).

Roentgen had the ability to work on various problems of physics because he had a great knowledge of literature and he read all the current publications (25). He had to put more effort into writing down his own observations for publications (25). Often he was involved in new discoveries and did not want to publish the results of old ones (25). He managed to publish nineteen papers by the age of forty-three while at Geissen (Grey 55).

On October 1, 1888, Wurzburg University offered Roentgen the post as professor of physics and director of the new physical institute (Glasser 26). Roentgen was forty-three years old and thrilled to return to Wurzburg after sixteen years to enjoy a social life with old friends (27). Wurzburg wanted Roentgen because he was known for designing instruments that could measure minute amounts in experiments (Grey 62). Like Michael Faraday, Roentgen did not use complicated calculations or any math in solving problems, he believed in keeping things simple (63). He preferred to work alone and did not use an assistant (63). After six years at the University he published seventeen papers

(Glasser 29). He studied the compressibility of liquids and discovered that there are two types of molecules: one was the ice molecules, which cause a larger volume, and the other was molecules formed with an increase in temperature and a subsequent decrease in volume (29-30). As always his interests were varied and never restricted to physics. In 1894, he was elected to the rectorship of the university (30). Ironically, the now famous scientist was working at the very university that would not give him the lowest ranking teaching position years ago (Grey 68). Roentgen commented on his newly acquired office at the university:

> …Pride in one's profession is demanded, but not professorial conceit, exclusiveness, or academic presumptuousness, all of which grow from a false estimation of one's self, rather a vital feeling of belonging to a favored profession which gives us rights but also requires many duties. All our ambitions should be directed toward a faithful fulfillment of duties toward others as well as toward ourselves only then will our university be esteemed, only then shall we prove worthy of the profession of academic freedom, and only then will this valuable and indispensable gift be retained.. (Glasser, 68).

Roentgen was not a prolific writer and by 1894 he had written less than fifty papers about his research (72). Roentgen had been the only individual able to test a twenty- year- old theory of the physicist James Clerk Maxwell (73). Roentgen had a great interest in electricity, and this led him to experiment with tubes. Around 1874, the Irish physicist Stoney named the negative charges in electricity, electrons (73). Vacuum tubes were the first tubes used. They would pump all the air out the tube and the wires were sealed in at both ends, one for the cathode, and one for the anode (75). Cathode rays were made up of electrons from the cathode (75).

An English physicist, William Crookes worked with the tubes and found they gave off a blue light against the tube wall and objects casted shadows (75). Heinrich Geissler invented the tubes that Roentgen used for cathode ray experiments (Glasser 34). Roentgen, like the scientist Lenard before him, again was able to confirm by his own experiments that invisible cathode rays emanated from the tube and did produce a fluorescent effect on a cardboard screen painted with barium plantinocynide, but only when it was placed near the window (35). He realized that in other experiments with heavier walled tubes, such as the Hittorf-Crookes fluorescence of a screen might also be caused by cathode rays, but it might also be obscured by the luminescence of the tube (35).

He decided to test the Hittorf-Crookes tube. He started the induction coil and passed a high-tension discharge through the tube. He saw a weak light shimmer on a nearby bench a yard from the tube (36). He decided to discharge the tube again and he saw the same fluorescence with faint green clouds floating with the pulsating discharges of the coil (36). Roentgen discovered the source of the light was the barium plantinocynanide screen on the bench. He continued repeating the experiment with the screen farther and farther away from the tube (36). His first observations of this were made on Friday, November 8, 1895 (37). His first notes were not recorded until a few days later. He named the rays x-rays, because x stood for the unknown (Grey 78). He moved into his laboratory so he could work continuously experimenting with the x-rays (80).

He found that thicknesses put in the path of rays showed variable transparencies when recorded on a photographic plate (Biography-Wilhelm 2). He distinguished an outline of his thumb and finger on one plate with a darker shadow of the bones of his hand (Glasser 38). He continued experimenting until he was absolutely certain of his observations. He did not want anyone to dispute his work. In the final weeks of 1895 he had built up enough evidence to hand it over to other scientists to confirm it (39). One evening he placed Mrs. Roentgen's hand on a photographic plate and took a fifteen-minute exposure (39). He wanted to publish his work as a quickly as possible. Seven weeks past his discovery of x-rays he searched for a magazine to publish his findings (Grey 85). He sent a preliminary paper to the Physico-Medical Society of Wurzburg on December 28, 1895 (86). It was published January 1896 (86). His paper was titled: *On a New Kind of Rays,* a preliminary communication, he requested it be published in the *Sitzunos-Berichte* of the society (Glasser 40). He chose physicists that were friends to do critical evaluations of his work. When it was thoroughly evaluated, letters of congratulations overflowed his office.

Tubes and other equipment were sent for the production of x-rays (54). People came from all over to observe Roentgen. Mrs. Roentgen complained that they had no peace at home. Since their residence was within the institute, people descended upon their home as well as the laboratory (55). Visitors pilfered x-rays from his lab and postcards with his signature never reached their destination (55). Bertha complained to her cousin Louise Roentgen-Grauel, who lived in Indiana in a letter dated March 4, 1896:

> Wilhelm has so much work he doesn't know which way to turn. Yes, dear Louise, it is not a small matter to become a famous man, and few people realize how much work and unrest this carries with it. When Wilhelm told me in November that he was working on an interesting problem, we had no idea how it would be received, but as soon as the paper was published our domestic peace was gone (Grey 101-102).

Roentgen had sent a set of x-rays to a friend Franz Exner, a professor at the University of Vienna (88). Exner turned the news over to his father Z.K. Lecer, the editor of the newspaper, *The Presser,* and news spread throughout the world (89). He gave his only lecture on x-rays to a large group on January 23, 1896, to the Physico-Medical Society (98). He was particularly pleased with the recognition he received in Berlin (Glasser 55). On January 4, 1897, they put reprints of Roentgen's x-rays in a temporary exhibit at the physical institute of Berlin University on the occasion of the fifteenth anniversary of the Berlin Physical Society (55).

Like his wife, Roentgen disliked all the publicity. The newspapers printed stories all over the world embellishing the discovery with speculations of their own about x-rays (58). Roentgen was unable to work for four weeks after the outbreak of the news of his discovery (62). He refused interviews with anyone except an American reporter H.S.W. Damm who wrote the article, *The New Manuel in Photography* for the 1896 issue of *McClure's* magazine (Grey 101). His colleagues proposed that the rays he discovered be called Roentgen rays, but he was opposed to this.

Roentgen wanted to pursue experiments on the rays themselves and not upon the medical uses. He had a lot of discussion with Albert Von Kolliker, the famous anatomist (Glasser 66). He let him know that he had x-rayed a dog and a cat without difficulty, but felt the obstacle to the medical development of x-rays existed because the body's organs were of the same density and could not be differentiated from one another (66). He expressed an interest in helping others experiment to benefit the medical field (66).

Tubes were very sensitive and were often destroyed in an experiment (63). It took four days to evacuate a new one (63). Ten weeks after his first paper on x-rays he completed his second on March 9, 1896 (Grey 103). In 1897, he published his third paper on x-rays (111). Two events occurred that Roentgen was especially proud of; he was given an honorary doctor of medicine by the University of Wurzburg, and he was given a tribute from the Wurzburg students who had paraded with torches to recognize his discovery of x-rays (Glasser 75-76).

Roentgen was an excellent teacher. His rule was that "the experience of life itself was the real test of capacity for any kind of profession" (120). He was a recipient of the Golden Rumford medal from the Royal Society in London (121). He gave it up during World War I, to be melted down (121). The Nobel Peace Prize he received was the first Nobel Prize awarded. The prize was thirteen thousand dollars and Roentgen gave it to the University of Wurzburg (Grey 119). He wanted his discovery to belong to the world, and took no profit from patents.

On April 1, 1900 he accepted a position in the new physical institute at the Ludwig-Maximilians University in Munich (Glasser 121). This move slowed down his research and publications. He continued to experiment with crystals and collaborated with the Russian physicist, Joffe (123). He looked at how x-rays affected crystals and their electrical conductivity (123). He often delayed publication on his research for too long because he feared an experimental error (124). The United States gave Roentgen two tributes (124). He received the Barnard medal from Columbia University and the Carnegie Institute in Washington offered him equipped laboratories to work in (124).

In the years that followed Roentgen's responsibilities increased along with teaching and researching. His wife became chronically ill with renal colic and World War I broke out (127). Bertha's pain was so intense that Roentgen had to give her up to five morphine shots a day (127). She died on October 31, 1919 (127). They were married almost fifty years (127). He continued to read the daily news to her picture and celebrated her birth and death dates (128).

In 1913, after strenuous exercise he suffered lung hemorrhages (128). He lost most of his fortune, because he changed his foreign investments into German War Bonds (129). This was really not by choice; the government would have fined him if he did not change his money over to German currency (130). Roentgen turned seventy when he received the Iron Cross in recognition of discovering x-rays that helped wounded soldiers (132). Roentgen was happy he helped the wounded of war. During the war Roentgen found it difficult to survive on his salary. The Germans were jobless; roughly 15 million were unemployed (Grey 125). One dollar was equal to four marks (125). A loft of bread cost sixteen dollars (125). One pound of butter ran around $360.00 (125). Roentgen rationed food willingly but refused to give up pipe tobacco (126).

He remained professor emeritus in 1920 (Glasser 132). Two labs were still reserved for his work at the physical institute, and he served as Conservator of the Physical Metronomical Institute of the Munich Academy of Science (132). He worked at the University up until a few days before his death (134). He died of carcinoma of the colon on February 10, 1923 (141). It had been purely by accident that Roentgen had protected himself from x-rays (Grey 139). In his experiments he used zinc-lined boxes and lead plates that stopped the rays (139).

In his will he gave 339 billion paper marks to the poor of Weilheim (132). He gave the city of Lennep, his birthplace, 3,654 gold marks to establish the Professor Doctor Roentgen Foundation (132). This foundation helped one group of poor and needy in the city of Lennep, people who were unable to finish school or get an education (132). His addresses and diplomas were given to the University of Wurzburg to be preserved (Glasser 140). His x-ray tubes went to the Deutsches Museum in Munich and according to his will, all scientific and personal writings were to be burned after his death (140).

RŒNTGEN

Antoine Henri Becquerel was the third generation of physicists in his family born in Paris on December 15, 1852 (McMurray 133). He attributed his successes in the laboratory to his upbringing by physicists (Broca 770). His grandfather, Antoine Cesar Becquerel, invented an electrolytic method for extracting metals from their ores (Hussey and Rand 1). His father, Alexandre Edmond Becquerel, invented the phosphoroscope (Broca 770). Although his family name assured him a position and a means of fast publication, it also allowed him to be a risk taker. He worked daily laboring in the laboratories.

In his early years he attended Lycee Louis-le-Grand School and graduated in 1872 (McMurray 133). When he was a young man on vacation from school, he was allowed to watch his father do old and some new experiments; and then permitted to duplicate those he thought he could handle doing (Broca 769). In 1873, at the age of nineteen, he entered the Ecole Polytechnique (770). When he turned twenty-two he entered the Ecole Ponts et Chaussees, and the following year he graduated from the Ecole Polytechnique (770).

In 1874, he married Lucie-Zoe-Marie Jamin, who died shortly after giving birth to their son, Jean (McMurray 133). Becquerel also suffered the loss of his grandfather two months before his wife (133). After their deaths he threw himself into doing a variety of research.

While at the Ecole des Ponts et Chaussees he became interested in Michael Faraday's experiments on the effects of magnetism on light (133). In 1845, Faraday discovered a beam of light experiences a rotation of planes when it passes through a magnetic field, which became known as the "Faraday effect"

(133). In his first published piece in 1875, Becquerel explained a formula he developed to show the relationship between the rotation and retraction the beam of light sustains, attempting to find the "Faraday effect" in gases (133). He discovered that gases, like solids, have the ability to rotate a beam of light (133). In 1879, he studied the magnetic properties of several materials and published this information on nickel, ozone and cobalt (133). At this time he also discovered that when nickel-plated iron is heated to a redness it becomes magnetic (133).

When Becquerel turned thirty he entered the Academy of Sciences (Broca 769). He often constructed his own devices from whatever he had available to demonstrate his discoveries. Many scientists came to see his laboratory and thought that it was "awful barren to allow him to be so productive" (769). He often entertained friends turning everything into physics with little or no difficulty (769).

Even though he received most of his education in the sciences, he was also very artistic (770). He had an ancestor, Girodet, who produced some masterpieces (770). Becquerel, a man that held high morals and despised deceit; was noted for being very tolerant of people, especially when they expressed opinion about his work (770).

In the 1880s he took up the research on luminescence that his father had been working on (McMurray 134). He was awarded his doctoral degree in 1888 from the Sorbonne at the age of thirty-five (Quinn 141). In 1890 he married for the second time, to Louise-Desiree Lorieux, a mine inspector's daughter (McMurray 134).

After spending five years in administration, he then went back to research and the laboratory (Quinn 141). In 1891, his father died and he succeeded him as Professor of Physics at the Museum of Natural History (McMurray 134). He became chief engineer at the Ecole des Ponts et Chausses in 1894 (134).

Bequerel's early experiments involved: the phenomenon of phosphorescence, the plane of light and the subject of his doctoral thesis, the absorption of light by crystals (Biography Henri 1). All of his previous works were over looked because of his discovery of natural radioactivity in 1896 (1). Part of his inheritance from his father included a supply of uranium salts that would phosphoresce after exposure to light (1). The Academy of Sciences members met every Monday, and whatever Becquerel chose of interest to be put in print, was printed ten days later (Romer 7). Henri Poincare, a mathematical physicist and two other physicians came to the Academy and submitted a copy of Roentgen's paper along with an x-ray of a hand for his inspection (7). Becquerel examined both with great interest. Becquerel wondered if all x-rays were always related to luminescence.

He began trying to find out by placing black paper around photographic plates and attaching potassium uranyl sulfate onto the top of them (McMurray 134). When they sat in the sun, he found that they were exposed; so he concluded that the sun had caused the uranium salts to glow and give off x-rays (134). On February 24, 1896, he reported his results at the Academy of

Sciences (134). On the 26th of February he wrapped more photographic plates and again taped uranyl sulfate to them (134). However, the sun was not shining, so he put them in a drawer (134). The next day he prepared them again, but the sun was still not out, so he stored them in the drawer as well. Though he did not expect any exposure to the plates, he developed them on March 1, 1896 and found that they were fogged (135).

Becquerel realized some type of radiation, not x-rays, had been emitted from the uranium salts and exposed the plates (135). Becquerel's rays were overshadowed by Roentgen's x-rays and people did not recognize them as a separate phenomenon. Marie Curie, a graduate student of Becquerel's found his rays as a good topic of study for her doctoral thesis (135). Marie stated; "The subject seemed to us very attractive and all the more so because the question was entirely new and nothing yet had been written upon it" (Quinn 143).

Becquerel continued to study uranium and found that the rays had the ability to ionize gases; and they were unique compared to x-rays because they could be deflected by magnetic or electric fields (Biography Henri 1). He shared the Nobel Prize in 1903 with Marie and Pierre Curie (1). He received it for discovering natural radiation, and the Curies' received it for their research on the rays (1). Becquerel also found uranium to be extremely more radioactive than the compounds of it and he began researching with it in May 1896 (McMurray 135). Throughout 1896 he published a total of seven papers on radioactivity and only two papers in 1897 (Badash 3). He published his findings on uranium in the *Anneles de Physique et de Chimie* and the *Comptes Rendus* *de l Academie des Science* (Biography Henri 1). Bequerel's final contribution concerning radiation was it's physiological effects (Badash 3). He put out his report in 1901 with Pierre Curie (Broca 785). Becquerel was burned by a sample of radium, after carrying it in his armpit for several hours (785). He contracted a severe ulceration, which took a long time in healing (785).

He continued to publish his work until his death. He became a physics lecturer at the Ecole Polytechnic School while he was still an engineering student (Broca 770). Later in 1895, he became a Professor of Applied Physics (Biography Henri 1).

Throughout his lifetime he was given numerous honors and awards; he also belonged to several scientific groups (Broca 770). Some of the medals he received included: the Helmholtz medal of Berlin, in 1901, the Nobel Prize in 1903, the Rumford Prize of London in 1900, and the Bernard medal of the United States in 1903 (770). He was made president of the Academy of Sciences in 1908, and honorary member of the Societe Francaise de Physique, which allowed him the privilege of being named permanent secretary (770).

Becquerel

Archives Photographiques

http://www.elmhurst.edu:8081/nobel/micro/59_13.html

Marya Sklodovski was born November 7, 1867 in Warsaw, Poland (Hallock 3). She grew up in a poor family and endured many hardships in order to study science in Paris. While in Paris she met Pierre Curie and they were married. After many years of experimenting they discovered the substance radium. It is used today to relieve discomfort and save lives from cancer. Marya became known worldwide as Marie Curie. Her parents belonged to the lesser landowning nobility and were very poor. In the 18^{th} and 19^{th} centuries Russia, Germany and Austria had each taken a section of Poland (3).

Marie grew up in the part that was under the rule of Alexander II, Tsar of the Russians. All Polish children were to learn Russian history and language instead of their own. Russian spies reported any resentment or signs that were interpreted as resistance to Russian rule. Marie grew up in a family of five children, four girls and one boy (4). Her pet name was Manya, and she was the youngest of the five children. Her father was a professor of physics in an all boys' high school. The family lived in a wing of the high school building.

When Marie reached six years of age her father's salary was reduced and he lost their lodging within the high school (5). The Russian authorities took away his privileges because they did not find him humble enough. The family was forced to move to a small home and take in young boy boarders. Then typhus struck and both of Marie's sisters, Bronya and Zosia came down with the fever. Zosia died, and two years later Marie's mother died when Marie was only ten years old (5). Her mother and older sister had been gone for two years traveling to Austria and the south of France in search of a cure for her mother's tuberculosis (Quinn 33). Her mother finally gave up the search and returned home in the midst of the typhus outbreak. Marie was a bright child, learning to read at the age of four (Hallock 5). She had a great memory and though she was the youngest in her class, she was the first in all that they studied (5).

In 1882, Jadwiga Szczasinska-Dawidowa started an all girls academy (Quinn 65). Two hundred students, including Marie met in secrecy (65). They outwitted the Russian police for one year (65). The school was formalized into what became known as the Flying University (65). In the years 1889-90, over a thousand women were enrolled in Warsaw (65). The instructors were finally forced to leave Poland in 1883, when Marie graduated from the government school. She was awarded a gold medal for scholarship (Hallock 6). Marie had to change schools because the government schools were the only ones that granted recognized diplomas (6).

Her father, Vladislav Sklodovski could barely pay for rent and food working as a professor, so all the children had to contribute. He had lost all his savings by investing with his brother in a mill (Quinn 24). He felt terrible guilt and believed he denied his children the financial support they needed for a good education (24). Marie earned her living giving private lessons to the children of wealthy families. She was able to continue studying by taking night classes taught by Polish teachers for free (Hallock 7). At this time the university was closed to women. Her sister Bronya longed to go to Paris to study medicine at the famous French University called Sorbonne (7). Marie went to work as a governess for a family to help put Bronya through medical school. She sent one half of her salary every month to Bronya (Curie 74). She went to work in Warsaw so she could be near her father. At the end of her workday she would teach peasant children to read and write. She organized her own little school. Her social class regarded working merely for the sake of money as degrading (Quinn 28).

Marie and her parents were positivists. Positivists believed in gradual progress accomplished through encouraging work, moderation and order to evolve the social system (64). Marie believed the power of education was a way to change society (64). In 1923 she stated: "that the ideas which inspired us then are the only way to real social progress." "You cannot hope to build a better world without improving the individuals" (64). Marie accomplished two important things during these difficult years: she worked as a governess and still managed to teach Polish peasant children, and she continued self-educating herself to reach the level of French students at Sorbonne (70). The Tsars had attempted to pit the polish peasantry against the upper class polish for an untapped source of national strength (71). The polish positivists believed that they must educate the polish peasants so they could be integrated into the polish nation (71). Marie contributed to this through her small class of students.

In 1891, Marie went to Paris to study at the Sorbonne (Hallock 9). Mlle Dydynska, who ran the flying university, helped to get Marie the Alexandrovitch scholarship (Curie 114-115). This scholarship was given to students who wished to study abroad (115). This amounted to six hundred rubles, enough for Marie to live on for fifteen months (115). Many years later, Marie gave the six hundred rubles back to the foundation (116). Her father acquired a job that paid him enough that he could help his daughters. Bronya married a young Polish physician and practiced in Paris (Hallock 9). She headed back to school at the age of twenty-four (9). Her chosen courses were: physics, chemistry and mathematics (11). She also did laboratory work and learned the manual dexterity and precision necessary for experimenting (11). She loved the laboratory work.

In July 1893 Marie graduated with a Masters degree in physics, then went on to work towards a Masters degree in mathematics (11). She was one of two female licensed recipients to receive the physics degree (Quinn 96). A year later when she completed her mathematics degree, there were only a total of five women to do so (96). Marie was able to ignore these differences and study uninhibited because she had such excellent teachers that kept her interested. Among Marie's professors were: Gabriel Lippmann, who invented a method of photo color reproduction and won a Nobel Prize in 1908, and Henri Poincare, the preeminent mathematician of the late nineteenth century (100). Marie never dwelled on how unusual she was, because she was so intent on fitting into this male world.

Historian Jules Michelet stated that French women during that time seldom left their homes without an escort and it was considered of "the worst fate for a woman to live alone" (92). If women ventured out unescorted in the evening, they were considered prostitutes (92). A woman never entered a restaurant to eat alone (92). Michelet wrote of this in 1860 and attitudes changed very little by 1891 (92). Michelet stated:

> France, in the last three decades of the nineteenth century, was moving toward some republican ideals, but equality for women was not prominent among them. The first president of the Third Republic was a monarchist who wanted to restore the Pope's temporal power. In reaction, republicans took control of French government and in 1877, passed a series of anticlerical laws. That was the beginning of a democratization and secularization of French life, which brought some benefits to women (93).

In 1891 when Marie came to France women had few opportunities (93). A woman could not even spend her own earnings without her husband's permission (93). The all male bourgeois club kept women from advancing in the nineteenth century (93). A popular writer at the time, Octave Mirbeau wrote:

> Woman is not a brain, she is a sex, and that is much better. She has only one role in this world, to make love, that is, to perpetuate the race. She is not good for anything but love and motherhood. Some women, rare exceptions, have been able to give, either in art or literature, the illusion that they are creative. But they are abnormal or simply reflections of men. I prefer what are called prostitutes because they are at least in harmony with the universe (93).

In 1892, when Marie enrolled in the Sorbonne, the number of women to men was 210 to a university population of nine thousand (96).

Marie met a French scientist named Pierre Curie at the home of a friend. He seemed young to her, but he was actually thirty-five years old (Hallock 12). It took him quite a while but he persuaded Marie to marry him on July 26, 1895 (12). Her brother-in-law's mother gave her a wedding gown as a gift (13). Marie was quoted as saying; "If you are going to be kind enough to give me one, please let it be practical and dark, so that I can put it on afterwards to go to the laboratory" (13). Marie and Pierre lived in a small three room flat, without extra chairs for visitors who might disturb their studies (13). She worked ten hours a day, spending eight hours on research and two hours on housekeeping (Curie 145). The Curies' would often stay up until two or three in the morning researching and taking notes (145).

Pierre earned around one hundred dollars a month teaching at the School of Physics. Marie worked in the laboratory of Pierre's school where a place was found for her. She studied the magnetic properties of various steels (Hallock 13). This was funded by the Society for the Encouragement of National Industry (15). At the same time, Marie was studying for an examination that would allow her to teach in France (13).

After they had been married two years they had a baby girl named Irene. Dr. Eugene Curie, Pierre's father delivered the baby (Curie 149). Pierre's mother died two days after Irene's birth and Dr. Curie move in with them (151). He watched after Irene and contributed greatly to her early education (151). Marie would have both a family life and a scientific career.

In the year 1897, Marie had accomplished two university degrees, a teaching diploma and a study on the magnetic properties of steels (152). She looked about to find something that interested her to research next and was fascinated by a discovery made by Henri Becquerel. Many substances would fluoresce when exposed to light and Henri Poincare, the French mathematician suggested researching these substances to see if the rays produced by fluorescent substances were similar to x-rays (Hallock 14). Henri Becquerel began the study with uranium. In the beginning of 1896, William Conrad Roentgen announced his discovery of x-rays; this was a few weeks before they began studying uranium (14).

Becquerel began by placing uranium salts on a photographic plate and exposing them to the sunlight (15). He found that after developing the plate there were spots on it where the salts had laid (15). Later he put a photographic tray containing uranium salts into a dark drawer and left them for days (15). When he remembered to remove the plate he found the same kind of dark spots on the plate (15). More experimenting proved that invisible rays were emitted spontaneously from the uranium compounds whether they fluoresced or not (15).

Marie was greatly interested in the discovery of Becquerel's rays. This realm of science had barely been touched upon. She began by measuring radiant energy from uranium. These rays made the air a conductor of electricity (15). They were able to measure the energy by the electric current that passed through the air. Pierre Curie and his brother Jacques created an electrometer to measure the energy of the rays (16). She discovered that uranium was not the only chemical element giving off rays. She began measuring all chemical elements or compounds of elements known at the time (16). She found that thorium also gave off rays like uranium. She then coined the term radioactivity for the energy given off by thorium and uranium (16).

Unbeknownst to the Curies', a German scientist, Gerhard Carl Schmidt had reported the activity of thorium to the *Deutsche Physikalische Gesellschaft* on March 24th, nineteen days before Marie's announcement to the Academy (Quinn 149-150). So although Pierre was more cautious when it came to speedy publication, Marie was always quick to publish her discovery after this incident with Schmidt (Pycior, Slack and Abir-AM 50). However, the Curies' were very systematic, and they quantified the energy given off by uranium and thorium with an ionization chamber (Quinn 145). Her labor and search for a cancer cure were of less importance than discovering that radioactivity was an atomic property of various elements (Hallock 15). This eventually led to our understanding of the structure of the atom (15).

The School of Physics had a collection of mineral specimens that Marie tested for radioactivity. She found the most powerful radioactivity came from an ore called pitchblende found in Austria (16). The Central Products Company treated the pitchblende that was donated by the Austrian government to the Curies' (Marie 2). This same company marketed Pierre's scientific instruments he created (2). Pierre was so impressed with the work Marie was doing; he dropped his work with crystals to help pursue an element mixed with pitchblende ore that would have more radioactivity than uranium or thorium.

In July 1898, Marie discovered the existence of one new element that she named polonium in honor of Poland (Hallock 17). Marie was awarded the 3,800 franc Prix Gegner citing her work on magnetic properties of steel and her discovery of polonium and radioactivity (Quinn 153). Eduard Suess, a Viennese geologist and member of the French Academy, intervened on the Curies' behalf with the Austrian government to obtain the pitchblende they sorely needed (155). Baron Edmond de Rothchild made many financial donations in support of their work. The first donation he made went towards procuring ten tons of pitchblende residue left after the extraction of uranium (155). It was frequently publicized that the French scientific establishment treated the Curies' poorly, and that they were only celebrated abroad (174). However, the Academy of Sciences of the Institute was quite generous financially in supporting the Curies' (174).

Marie was awarded the Prix Gegner thrice, and in 1903 Pierre won the coveted ten thousand franc biannual Prix La Caze (174). In March of 1902, the Academy of Sciences made a twenty thousand franc credit available to the Curies' for their work in purifying five tons of ore to isolate radium (174). There were also many influential members of the Institute that actively supported their work. When Pierre was thinking of finding a commercial solution to their financial woes, Henri Becquerel helped to get Pierre a two thousand franc grant (174). Many powerful academicians and the Institute were generous with their financial support (174). Susan Quinn stated:

> What the Curies' wanted rather than piecemeal grants, was a home for their work; a well-equipped laboratory, generous salaries and the freedom from the need to cultivate connections and play politics. The French establishment, was unwilling to bestow such gifts upon this couple (175).

A couple of months later in December 1898, they discovered another element that they named radium (Hallock 17). They would labor for four years to prove the existence of radium (17). They had known of its existence because they found barium in the pitchblende. The mining of pitchblende had been done in the Joachimstal region on the German-Czechoslovakia border (Quinn 147). It was originally valued as a source of uranium that proved to be a superior coloring agent in ceramic glazes (147). Barium is not itself radioactive but it is associated with a small amount of something that made it radioactive (Hallock 17). Many chemists doubted that radium existed because they had never seen it.

The Curies' believed that some radium had to remain in the ore after the uranium was removed. They worked in an abandoned shack that belonged to the School of Physics (18). In the winter the temperature of the make shift lab dropped to around six degrees (Nobel 2). Marie's part in the search was to find the actual chemical treatments that would allow them to isolate pure radium. Marie wrote about their work saying:

> …I may say without exaggeration that this period was, for my husband and my self, the heroic period of our common existence. And yet it was in this miserable old shed that the best and happiest years of our life were spent, entirely consecrated to work. I sometimes passed the whole day stirring a mass in ebullition, with an iron rod nearly as big as myself. In the evening I was broken with fatigue (Curie 169).

It took years of work. In 1902, forty-five months after they announced the existence of radium, Marie succeeded in isolating a small decigram of pure radium (175). She also determined the atomic weight of radium to be 225 (175). They went down to the shed late one night and could see the particles of radium shining within their receivers (Hallock 20). Marie wrote:

> This luminosity cannot be seen by daylight. But it can be easily seen in half darkness. The light emitted can be strong enough

> to read by, using a little of the product for light in darkness (Curie 196).

In 1898, Pierre applied for the position of professor in the physical chemistry department at the Sorbonne (Hallock 20). He was turned down. They never allowed him to be a professor at Sorbonne until after he became famous. He found a job at an extension of the university where he taught chemistry, physics and science. Marie taught physics at an all girls' school at Sevres, near Versailles. Pierre suffered from severe arthritis and often had to cease working. Together, they published thirty-two scientific papers on the properties of radium from 1899 to 1904 (21).

Scientists rushed to search for other sources of radium and to study it. Then Henri Becquerel was burnt while carrying a tube of radium that the Curies' had given him. Becquerel and Pierre hastened to draw up their observations of radium on June 3, 1901 (Curie 199). Pierre had studied the effects of the rays on animals and collaborated with others to find that it destroyed diseased cells, tumors and certain forms of cancer (199). Marie and Pierre lent radium to others to investigate treatments.

Marie extracted the first gram of radium from eight tons of pitchblende (Hallock 21). She owned it and after her death it became the property of her laboratory (21). It was quite expensive to extract radium and it became a valuable substance worldwide. In the 20th century radium sold for $150,000 a gram (Curie 200). The radiation of the radium was two million times stronger than that of uranium (195). The rays from it could travel through the hardest matter. Marie had discovered how to manufacture radium. Engineers would not be able to produce it without knowing her delicate operation of extracting it.

Pierre encouraged Marie to publish how she treated the pitchblende and to patent the technique, so they would be assured rights over the manufacture of radium worldwide. American scientists were already writing the Curies' wanting information on how to produce radium. However, they both decided it would be wrong to seek a patent, even though they could improve their lives. They felt it was contrary to their ethics as scientists. Marie wrote:

> In agreement with me Pierre decided to take no material profit from our discovery: in consequence we took out no patent and we have published the results of our research without reserve, as well as the processes of the preparation of radium. Moreover, we gave interested persons all the information they requested. This was a great benefit to the radium industry which was enabled to develop in full liberty, first in France and then abroad, furnishing to scientists and doctors the products they needed. As a matter of fact this industry is still using today, almost without modification, the processes, which we pointed out (205).

In June 1903, they went to the Royal Institution to lecture on radium (206). Marie also completed her thesis on June 25, 1903 and received her doctorate (201). In November 1903, they received the Davy medal, considered the highest award given by the Royal Society of London (208). Then in December, the Curies along with Henri Becquerel received the Nobel Prize for their discoveries of radioactivity. Marie became the first and only celebrated woman scientist worldwide (210). Finally they were rewarded with some financial relief on January 2, 1904 (211). The prize consisted of seventy thousand francs or fourteen thousand dollars (210). With this money they hired a lab assistant and put a bathroom in their home (Hallock 23). She continued teaching but persuaded Pierre to leave the School of Physics.

Newspaper reporters swamped their home and their laboratory in the shed. Fame finally arrived in the form of: newspaper articles, requests for autographs and photos and invitations to numerous social events (24). The Curies' did not like fame, it interrupted their work and they had much to accomplish. Marie wrote her brother:

> …Always a hubbub. People are keeping us from work as much as they can. Now I have decided to be brave and I receive no visitors-but they disturb me just the same. Our life has been altogether spoiled by honors and fame (Curie 217).

On December 6, 1904, Marie had another baby girl named Eve (Hallock 24). The following year Pierre received the highest honor of a French scientist, he was elected into the Academy of Sciences (24). They offered him a chair in physics at the Sorbonne, but he wanted a finer laboratory (24). One decision that the minister made that greatly pleased the Curies' was allowing Marie to be chief of the laboratory (Curie 239). Marie had no rank or salary while researching radium, now she would be paid two to four hundred francs a year (239).

Pierre was killed in 1906 when he was run over by a horse-drawn carriage in the rain (Hallock 25). Marie was then offered her husband's position in physics at the Sorbonne. This position made her the first woman to hold such a job in France's higher educational system (25). She was the only woman allowed to take a chair at the Sorbonne, which had been in existence 650 years (25). After this she was offered many honorary degrees and memberships in foreign universities. She was promoted to the titular professorship in 1908 and gave the first course on radioactivity in the world (Curie 275). In 1911 she received the Nobel Prize in Chemistry, her second time (278). Against her father- in-laws advice she made her radium, which was worth more than a million gold francs, a gift to the laboratory at the Sorbonne (269).

The science of radioactivity was born and the Sorbonne joined the Pasteur Institute to create the Institute of Radium. The Institute of Radium consisted of two labs: one with radioactivity that Marie ran, and the other dealt with the treatment of cancer by radium (Hallock 26). When World War I broke out Marie was devoted to the war effort entirely. She even transported the gram of radium she gave to the laboratory to Bordeaux, where it would be kept safe (Curie 293).

Her expense book showed the charitable donations she made and there were regular entries for: polish aid, national aid, shelters for the poor, and yarn for soldiers (Quinn 260). Marie also took her second Nobel Prize earnings and invested them in French war bonds, where they lost almost all of their value (361). She had taken her medals to the Bank of France to be melted down, but they refused them (Curie 301). She thought it absurd that they refused to do so (301). “Caring for the wounded was the accepted role for middle-class women in this as in previous wars”(Quinn 361).

In 1895, Roentgen developed x-rays and this allowed for the detection of fragments or shells from a bullet in World War I (Hallock 26). Marie realized how important this was to surgeons and began collecting x-ray equipment from manufacturers and then distributed them to hospitals near Paris (Curie 291). Volunteers to operate the equipment consisted of educators, scientists and engineers (291). She created the first radiological car funded by the Union of Women of France and the French Red Cross (Quinn 362). The weight of all the x-ray equipment would come to about five hundred pounds (362). The generator to produce the x-ray weighed about two hundred pounds by itself (362). A cheaper solution was to have a dynamo that could be fastened to the car motor that could convert the power into electricity (362).

She equipped the car with the necessary x-ray equipment. She begged automobile body shops to convert cars into vans, and talked manufacturers into donating equipment (Marie 2). By October 1914, Marie eventually equipped twenty of these cars that were nicknamed "Little Curies" (Curie 295). She also installed two hundred radiological rooms in hospitals for the wounded (297). The 220 fixed or mobile posts created by Marie treated more than one million men (297). Marie described how the radiology car did its job during the war:

> Advised of a pressing need, the radiology car departs carrying all its supplies and its provisions of gasoline. That doesn't prevent it from moving at the speed of twenty five miles an hour when the state of the road permits it. The personnel consist of a doctor, a technician and a chauffeur, but on a good team each transcends his métier (Quinn, 363).

When the casualties of the Battle of Marne arrived back to Paris, Marie realized the need for radiology assistance at the front (363). "The lack of equipment and the lack of information at the beginning of the war permitted operations without radiological exam, which later, would have been considered criminal" (363). Others in the military supported Marie's efforts to reform the health service, and in October 1914 a private organization, the Patronage des blesses, was founded for that purpose (364). M.E. Lauisse, one of the Sorbonne circle founded the organization and appointed Marie as technical director of radiology, she then began to receive funding (364).

In November, 1914 Irene and Marie received permission to bring a second radiological car to Creil, twenty miles behind the front lines at Compeigne to set up their equipment (365). It took quite a while to receive permission to go to the front because it was frowned upon for women to serve at the front (365). As the war progressed the need for more technicians and radiologists grew. Marie was asked by the army to conduct a course for technicians. She proposed training nurses to be technicians (367).

In October 1916, a school for x-ray technicians opened at a new hospital named after "Edith Cavell, the English nurse executed by the Germans in 1915" (367). Many women from a variety of backgrounds entered the school. Some of the women were army nurses, some had an educational background, and some were maids (367). They were grouped into classes of twenty that trained for six weeks (367). The school turned out around one hundred and fifty technicians by the time the war ended (367). All of these students were placed at posts around the country (367). Marie stated in her notebook:

> They gave, in general, entire satisfaction in their work. Some found themselves obliged to provide radiological service in the absence of radiologists, and handled this task with such a conscientious effort that they earned the approval and entire confidence of their chiefs of service. This was a job women could do well (368).

War was a time that women were free for a change, to be out in the world doing things and it was exciting for them (370). In 1918, she was asked by the Italian government to study the countries resources in radioactive substances (Curie 303). After her mission in Italy, she was called to teach twenty soldiers from the American Expeditionary Forces about radioactivity (303). She taught apprentices for two more years during the war. She was then asked to write a book on her war experiences, she titled it *Radiology in War* (306). France had offered her the award of the Legion of Honor for her role in the war, but she refused it (307). She would have preferred to be rewarded the rank of chevalier as a soldier (307). Eve Curie stated:

> A great many ladies received decorations and rosettes. She was given nothing. After some weeks, the part she played in the great drama was effaced from all memories. And in spite of services, which had been somewhat exceptional, nobody dreamed of pinning the little cross of a soldier on Madame Curie's dress (307).

After the war had ended in May 1920, an American woman interviewed Marie and asked her, "If you had the whole world to choose from what would you take?" (Hallock 27) Marie replied: "I need a gram of radium to continue my researches, but I cannot buy it; radium is too dear for me" (27). She owned one gram of radium that she prepared herself, but it was being used in the Institute of Radium to cure cancer (27). The interviewer, Mrs. William Brown Meloney sent Marie a letter within the year stating that she had obtained the money for Marie to buy the radium. Women all over America had donated to buy it for her. They wanted Marie to come to America to receive it. At the age of fifty-four, her and her daughters decided to journey to America (27). It was the first time she accepted an invitation that involved publicity (27).

President Harding of the United States presented her with the gram of radium (27). Various gifts were exchanged between Marie and the United States. She received many honorary doctorates and the owner of a factory gave her fifty milligrams of mesothorium (Curie 332). Members of the Philosophical Society gave her the John Scott Medal; she reciprocated by giving them a piezoelectric quartz that she personally made and used in research (332). She grew weak after arriving in America and had to return to France earlier than planned. She returned a second time in 1929, to America to receive another gram of radium from President Hoover donated by admirers for the Marie Sklodovska-Curie Institute of Radium in Warsaw (Hallock 28). Her sister Bronya was the architect, agent and treasurer of the Institute at Warsaw. Bronya was now quite old, but Marie was ill and unable to oversee the project (Curie 342). Marie wrote Bronya in 1927:

> Sometimes my courage fails me and I think I ought to stop working, live in the country and devote myself to gardening. But I am held by a thousand bonds, and I don't know when I should be able to arrange things otherwise. Nor do I know whether, by writing scientific books, I could live without the laboratory (373).

In 1920, the year before Marie's visit to America, forty-one women in America were granted doctorates in science; three years after her second and last visit in 1932 there were 138 to do so (396-397). It is believed that Marie's visits inspired more women to enter the sciences (397). On May 29,1932, the Institute at Warsaw was completed (Curie 344). Bronya had used good judgment in designing the building and it had already been treating patients for cancer for several months prior to its inauguration (344). Marie visited Poland for the last time to attend this ceremony (344).

Marie's laboratory was supported by foundation grants and her salary was supplemented by a pension of forty thousand francs provided by the French government, "partly in response to America's generosity" (Quinn 387). Marie accumulated vacation properties all around France and the public began to see her as hypocritical after making claims of poverty in the press (387). Author Susan Quinn stated:

> Many quacks and opportunists traded on the assumption, and on the Curies' good name. There were claims for "Curie Hair Tonic" which not only stopped hair loss but restored hair to its original color, and of a "Crème Activa" which promised eternal youth, accompanied by the statement that "Madame Curie … promises miracles." A 1929 European pharmacopoeia listed eighty patent medicines whose ingredients were radioactive; they came in the form of bath salts, liniment, suppositories, toothpaste, and chocolate candies. But reputable physicians also believed in "radium therapy" for a range of illnesses besides cancer (409-410).

However, Professor Claude Regaud waged a war on cancer and between the years 1919 to 1935, the Radium Institute treated 8,319 patients (Curie 368). Today it is still very efficient, each year the hospital gives seventy thousand consultations and six thousand patients receive treatment (Nobel 5). The Curie Institute also has a proton therapy center to radiate tumors that are inoperable and gene therapy testing is conducted there (5). One of the most surprising applications of radioactive treatments came with the onset of World War I. According to author Susan Quinn, soldiers were injected intravenously with radium solutions in cases of blood loss, and they used applications of radon and radium to soften scar tissue and loosen joints (410).

Marie was proud to provide ampoules for such treatment from her lab (410). She used a technique that was discovered in Dublin to collect radon (Marie 1). Without using any protection she used an electric pump to collect the gas at forty- eight- hour intervals and then sealed it in glass tubes (1). Platinum needles were used to inject the contents of the tubes into diseased tissue to destroy it (2).

Toward the last years of Marie's life her main goal was not researching any more, but directing the Curie Institute. She formed groups of researchers; three or four dozen and she monitored the details of their work closely (2). One of her researchers was Salomon Rosenblum, who made a major discovery in 1929 when he confirmed the quantum theory (2). Marie had prepared the actinium for him to work with (2). Later on her own daughter and son-in- law would become well known for their work at the institute (2). At the age of sixty- five she continued to work twelve to fourteen hours a day (Curie 355). She also found time to serve on the commission on Intellectual Cooperation of the League of Nations. She worked to develop standards for scientific scholarships and strived to protect researchers rights for their discoveries (Marie 3).

In 1925, several painters of luminous watch dials began to show signs of radiation poisoning (Quinn, 411). Margaret Carlough was the first person to file suit against her employer, United States Radium Corporation of New Jersey, when she suffered irreparable damage to her health (411). Workers were dipping their paintbrushes into a solution of luminous radium and then putting their brushes back into their mouths, in order to paint detailed work on the watch dials. By 1928, fifteen workers had already died and many others suffered necrosis of the jaw and anemia (411). This was proof that radium was dangerous even in small amounts and it would lodge in the bones, instead of being expelled by the body as previously thought (411). Quinn stated:

> The levels of exposure now considered "safe" are a small fraction of what Marie Curie and her colleagues lived with in their laboratory. To suggest just how much more stringent standards have become, it is enough to say that papers that were kept at the laboratory had to be decontaminated before they could be made available to researchers at the Bibliotheque nationale, and some of them still cannot be inspected unless the reader signs a waiver. The hope with which radioactivity was greeted in the early years has been replaced by a fear sometimes bordering on the irrational (410).

In 1921, a report prepared by Marie Curie, Antoine Bedere and Claudius Regaud emphasized the dangers in working with radioactive materials and inhaling alpha particles (412). They also stressed using lead screens between the worker and the source (413). They proposed periodic blood tests to detect abnormalities in workers in the factories, lab and hospitals (413). They recommended that there be regulation of their suggestions by the Minister of Work and Health (413).

By 1931 seven out of twenty workers in Marie's lab showed signs of abnormalities in their blood (415). Irene showed signs of anemia as early as 1927 (415). During this time people believed fresh air would eliminate many illnesses, and Marie would send Irene on leave into the mountains hoping this would rejuvenate her. Many days Marie became to ill herself to go to the lab, so she worked on her last book called *Radioactivity*, which was published posthumously in 1935 (Marie 2). She left her laboratory in May 1934, never to return again (Hallock 28). On July 4,1934, it was announced that her work had ended because she was afflicted with a form of anemia caused by a long exposure to radiation (28).

Irene Curie was born to Nobel Prize winners Marie and Pierre Curie on September12, 1897 (Hussey, Rand 1). Marie had written that she was a “difficult baby”, yet called her “my little queen” (McGrayne 118). Shortly after Irene was born, her grandmother Curie died. Her grandfather, Eugene Curie moved in with Pierre and Marie, becoming Irene’s caretaker. Irene was a preschooler when Marie isolated radium (118). Eugene Curie taught Irene to take an interest in radical politics, poetry and nature. Like Marie and his son Pierre, he did not believe in strict academic and social restraints being placed on children (121). Later, Irene stated:

> My spirit was formed in great part by my grandfather Eugene, and my reactions to political or religious questions came from him more than from my mother. Politically, he was an anticlerical republican opposed to the power of the conservative French aristocracy and the Catholic Church (121).

Marie had told her daughter, “I raise you without religion but you will see later if you want to take one when you are older” (121). Irene never entered a church in her life, but respected others’ beliefs (121). All the crises in her life only served to bring her closer to her mother. When she was seven years old, her sister Eve was born, and sixteen months later her father was killed (122). She inherited her love of science from her parents (Byers, Moszkowski 4). She was outspoken, quite frank and conscientious about anything she set out to accomplish (4). Her interest in mathematics was apparent as early as the age of ten (Hussey, Rand 1). Marie tutored Irene in mathematics through letters when they were apart (McGrayne 123).

Marie had organized a cooperative school with the other scientists so they could teach their own children. She felt the French educational system was lacking (123). She believed children should be allowed the freedom to think and play, rather than just memorizing material (123). There were only ten children in the school and it lasted 2 ½ years (123). The friendships Irene developed with these children lasted her entire life (123). Marie taught Irene many unconventional skills that she continued to use throughout her life, horseback riding, mountain climbing, gymnastics, skating and swimming (122).

Irene idolized her mother. She never really understood her mother's fame until on November 8, 1911, when her mother received the Nobel Prize (124). For one year Marie lived away from her children. She battled a severe kidney infection and was on the brink of suicide, so she went into seclusion (124). She would not permit her children to see her, and she hired a governess to take care of them (125). Irene distrusted outsiders and like her mother, she had the ability to focus only on what was important to her (125). Things that she did not find interesting, she simply ignored (125).

Irene went to high school at the College of Sevigne in Paris (Hussey, Rand 1). In the summer of 1914, World War I forced Marie to move the children to L'Arcouest, a fishing village in Brittany (McGrayne 125). As the war continued Marie wrote to Irene, "Things seem to be turning bad...you and I, Irene, we must look for a way to make ourselves useful" (125). In October 1914, Irene attended the Sorbonne and majored in mathematics and physics

(Hussey, Rand 1). Irene begged her mother to allow her to return to France but Marie responded:

> My sweet dear. I sense how you have already become a companion and friend to me. If you cannot work for France today, work for it's future. Many people will be missing after this war; it will be necessary to replace them. Do your physics and mathematics the best you can (McGrayne 126).

Irene ended up leaving school to help her mother set up mobile x-ray facilities (Hussey, Rand 1). Irene could set up an x-ray unit in less than an hour (McGrayne 118). She was just eighteen when she was stationed at an Anglo-Belgian field hospital where she worked to convince Belgian surgeons that x-rays could pinpoint areas of fractures and shrapnel (117). Even though she was close to the front lines, Marie trusted her daughter to be there without any reservations (117). Irene stated," My mother had no more doubts about me than she doubted about herself" (117). During this time she managed to study for examinations and work on her doctoral thesis (118).

Upon Irene's return to France she assisted her mother in moving into the Curie Institute (126). Together with her mother, they began teaching women to be x-ray technicians for the many mobile x-ray stations they had set up. Irene taught around one hundred and fifty technicians how to calculate techniques and adjust the varied electrical systems of the French (118). In 1918, Irene joined her mother at the Curie Institute as her assistant (Hussey, Rand 1). She loved the research and never exhibited a competitive nature (McGrayne 126). Like Pierre, she worked in science for the personal joy it gave her, not for the success (126). She felt the reason she and her mother got along so well was because she was so much like Pierre (126). Her mother and her discussed things of equal interests such as: "poetry, theater, books, and the work at the laboratory" (126).

Irene had several interests such as dancing and athletics (127). She also went on fifteen day back packing trips each summer and went swimming in the river Seine (127). These were seen as men's sports in the 1920's, but the Curie women participated in them also (127). Her math abilities seemed extremely high for her age of twenty-five (127). Many co-workers were jealous of Irene's position at the Radium Institute and they referred to her as the "Crown Princess" (127).

In 1921, she went to the United States with Marie on a fund raising trip; where Marie would also be accepting a gram of radium from the United States (127). Irene often spoke in place of her mother at colleges and received Marie's honorary degrees (127-128). In 1925, Irene defended her dissertation on alpha particles emitted by polonium (128). She researched how the particles slowed down as they moved through matter (128). When she defended her thesis there were a thousand people in the auditorium; but Marie stayed home so she would not take attention away from Irene (128). She became only one in five experts in radioactivity during the 1920s (128). When asked by a reporter, " If a scientific career might not be too taxing for a woman? Irene replied, "Not at all. I believe that men and women's scientific aptitudes are exactly the same. A woman of science should renounce worldly obligations" (128). She considered science the ultimate interest of her life (128).

Marie wanted to remove Irene from the publicity and sent her to Algeria (129). Meanwhile, Marie was interviewing Frederic Joliot, an army officer that had no research training (129). Marie gave him a job based on Paul Langevin's recommendation (129). Fred was very different from Irene. He was an extrovert and loved being in the public (129). He was known as a "chain-smoking ladies man"(129). Their daughter, Helene Langevein-Joliot explained how they were different:

> Relationships between people were important to him; he would guess quickly if someone had a problem, and he wanted others to understand him. Mother could walk right through something and see nothing. If somebody didn't shake hands with him, he'd worry; my mother wouldn't have noticed. Connections with people were tighter and more complicated with him; they were a nuisance for my mother. My mother was very like Pierre Curie, more stable. She needed time to think, and she'd do only what she wanted (129).

They tended to agree on the important issues and respected each other's abilities (129). They became partners in the laboratory. Irene became engaged to Fred when she was twenty-eight years old (130). They were married on October 29, 1926 (Hussey, Rand 2). Later, Marie gave them an apartment in a complex known as the Sorbonne Beach Annex where many other scientists lived (Pycior, Slack and Abir-AM 61). Marie had insisted that Irene have a marriage agreement because at the time French law allowed husbands to take over their wives property (McGrayne 130). Marie also had it written in her will that Irene would inherit the use of the radium at the Institute (130). At first Marie did not like Fred, she introduced him as, "the man who married Irene" (130). As time went on Marie warmed up to her son-in-law, Irene stated:

> My mother and my husband often debated with such ardor, answering back and forth so rapidly, that I couldn't get a word in and was obliged to insist on having a say when I wanted to express an opinion (Quinn 426).

Within twenty years Fred would be considered one of the most powerful men in France (McGrayne 130). In the couples scientific publications he used F. Joliot and she used Irene Curie, socially they both used Joliot. However for political statements and popular articles they used Joliot-Curie (130). They published thirty-three papers together; they worked as a team for five years (Pycior, Slack and Abir-AM 57). They started working together three years after they were married and concentrated their research on the rays of polonium (62). The English nicknamed the couple the "Jolly-Curios" (McGrayne 131). After the birth of her children, Irene felt she now had everything, her family and research.

She was a feminist that managed to be a mother, scientist and a professor. She taught in the Faculty of Science in Paris (Biography-Irene 1). She was more traditional in her role as a mother than Marie; because there were many times Irene and Eve were left in the care of others (McGrayne 131). Author Bernadette Bensaude-Vincent stated:

> Though tenderly loved by her grandfather, the young Irene could not help but feel lonely, often abandoned by her parents, who spent most of their time with their other child: radium. Jealous of radium, then jealous of her younger and prettier sister Eve (born in 1904), Irene came to demand exclusive love from her mother, apparently trying to capture her mother's attention through what is now termed anorexia (Pycior, Slack and Abir-AM 60).

After Irene gave birth to her daughter Helene on September 17, 1927, she was diagnosed with tuberculosis and fought it continuously for twenty years (McGrayne 131).

They were in financial trouble until the French government began investing in research (131). With the rise of Fascism, Fred, was able to get a government grant and go into research full-time with Irene (131). Together they produced the most powerful supply of polonium (131). This type of work was very dangerous; later scientists found out that toxic polonium concentrates in the liver, lungs and spleen (132). Unfortunately, they both often mouth-pipetted radioactive materials (132). The Joliot-Curies were determined to continue working. Other scientists started reading the French journals just to see what they were doing (132).

In the 1930s they had heavy competition that included Lise Meitner at the Kaiser Wilhelm Institute in Berlin, Ernest Rutherford in England and Neils Bohr in Copenhagen (132). They were quick to send out short publications every two weeks (132). At this time the neutron was not discovered; scientists believed the atom consisted only of electrons and protons (132).

Irene set out to focus on an experiment done by physicist, Walther Bothe (132). Bothe bombarded beryllium with particles of polonium and rays emerged powerful enough to penetrate lead two centimeters thick (132). Irene began to study the rays. She placed different objects in the path of the rays. She placed paraffin wax in the way of the rays and the wax speedily ejected protons (132). Fred and Irene surmised incorrectly that the rays had to be gamma rays; and they published an article stating this in January 1932 (132). On March 12, 1932 their son Pierre was born (Hussey, Rand 2).

James Chadwick discovered the neutron when he replicated the research of the

Joliot-Curies (McGrayne 133). Marie's element polonium allowed for the detection of the neutron because it was a source of alpha rays, not gamma rays (Quinn 426). Because of these discoveries scientists understood that the atom was composed of protons and neutrons, the foundation of nuclear physics (McGrayne 133). The Joliet-Curies

failed because they misinterpreted their data (133). They began studying neutrons with a Wilson cloud chamber that had the ability to photograph atomic collisions and their pathways (133). Like Pierre Curie, Fred was extremely good at designing instruments (Pycior, Slack, and Abir-AM 62). He built an approved model of the Wilson cloud chamber in 1931 so they could visualize ionized particles through a gas (62).

Once again they guessed wrong about what they observed. They saw a positively charged particle that they surmised was either a negative charged electron that went toward the neutrons; or a positron that would prove to be antimatter (McGrayne 133). Months later, C.D. Anderson replicated the experiment and won the Nobel Prize by proving the particle to be a positron (133). Irene did receive a nomination for the Nobel Prize for contributing to the discovery, but Anderson won it (134).

Later, in 1934, they redid an old experiment where they placed polonium next to aluminum foil and neutrons with positrons emerged (134). They discovered with a Geiger counter that neutrons stopped but positrons continued to emerge from the aluminum foil (134). They realized by the sound of the clicking on the Geiger counter it was radioactivity being emitted (134). The aluminum had changed into an artificial type of phosphorus, but it was an unstable element and took the form of silicon (135). In it's final form the naturally stable element became artificially radioactive (135). Irene created a three- minute chemical test that proved the aluminum changed into phosphorus and then silicon (135). The phosphorus would decay within three and a half minutes (135).

This brought the greatest joy to Marie Curie who knew this meant a Nobel Prize for her daughter and son-in-law (136). She died a few months after their discovery (136). In 1934, they were nominated for the Nobel Prize, but did not win it until 1935 for their discovery of artificial radioactivity (136). More than four hundred isotopes were found after their discovery, changing the periodic table (Hussey, Rand 2). Several years later these isotopes were used for weapons, medicine and other research (3). It proved to be a frustrating time for Irene, since the press contributed most of the discovery to Fred and stated that she assisted him in the laboratory (136). It was still a victory that they had won, bringing the total in Nobel Prizes to three in the family (136). Later it rose to four when Eve, Irene's sister married diplomat Henry R. Labouisse and he won the Nobel Prize in 1965 for the United Nation's Emergency Children's Fund (136).

Irene and Fred were able to distinguish what each of them contributed when they gave their Nobel Prize lecture (136). Irene gave the physics portion and Fred gave the chemistry portion (136). The prize money paid for a new home and tennis court on property Marie had purchased years earlier (136). Shortly after they received the Nobel Prize, Fred went to work for the College de France and Irene became involved in politics. This ended their teamwork in the laboratory.

While Fred became involved in building a cyclotron and worked on accelerator designs, Irene was the research director at the Radium Institute and taught at the University of Paris (137). She began to join many women's rights organizations. She stated: "I am not one of those.. who think that a woman scientist can disinterest herself from her role as a woman, either in private or public life"(137). She defended the rights of women to work and pointed out that there are women who are divorced or widowed that need to work (137).

She was offered the job of Under Secretary of State for scientific research for the Popular Front (137). The Popular Front was a combination of Socialists, Communists, and French Centrist Moderates that were antifascists elected in 1936 (137). Irene was the first female cabinet minister in France (Pycior, Slack, and Abir-AM 67). She hoped to motivate other women to participate in politics by taking the position as cabinet minister (67). She grew bored with political work and found it to be too difficult to handle with her responsibilities at the laboratory, so she arranged to have a friend take over two months later (68).

At this time in France women could not even vote (McGrayne 137). Irene belonged to the World Peace Council and a woman's group known as Comite National de l' Union des Femmes Francaises (Biography Irene 1). Irene wanted the same rights exercised for qualified women as the men in the professions have with the same experience and education (McGrayne 137). She did not waste money, time, or energy on anything, especially the newest fashions (Hussey, Rand 2). She cut her own hair and wore black dresses like her mother (2). She hated formalities, and many people found her to be unsuitable for public relations (Pycior, Slack and Abir-AM 60). If she attended a meeting that failed to get to the point or had a direct purpose, she would simply get up and leave (McGrayne 138).

She remained conventional in her opinions regarding women's suffrage (Pycior, Slack and Abir-AM 68). She was like Marie in her underlying goal; she wanted social progression above all things (68). She stated,

> I think that the decision of giving women the vote is a measure of justice that has been too long delayed. Indeed one can expect that a great majority of the female electorate is not prepared for its social role. The problem is unavoidable in the beginning; it is because women have been banished from political life that many of them are not interested in it. The only argument that catches my attention against women's suffrage is the following: in several countries, women's votes contributed to the election of reactionary deputies who promptly reduced the civil and economic rights of their electresses. Hence the paradox: in several countries where women were allowed to vote, they became economically more dependent than in France, where they did not have the vote. Nothing like that will happen in France, because of the changes that occurred in political life during the war. However we have to be vigilant, for

> usually antifeminists, whether men or women, are also against progress in general (68).

After the Popular Front failed to aid the Spanish Republican government against the Fascist revolt, the Joliet-Curies pulled their support from the party (McGrayne 138).

In the 1930s, Irene's tuberculosis grew worse and she spent many months in the Alps trying rest cures (138). It was believed that her radiation exposure in World War I and exposure to polonium in the laboratory; probably lowered her immunity and she was unable to fight off tuberculosis (138). She passed the time reading Rudyard Kipling, mysteries and her favorite book, *Gone With the Wind* (138). She stayed with the family tradition of having a Sunday open house dinner; every Sunday she served a dinner at one o'clock for twenty or more family and friends (138).

In 1938 she went back to work and nearly won a second Nobel Prize when she discovered but did not fully identify the isotope of Lanthanum (Byers, Moszkowski 2). With Fred being employed by the College de France, she took on a young Yugoslavian laboratory assistant, Paul Savitch to work with her (McGrayne 138). At this time scientists were trying to figure out what happens when uranium is bombarded with neutrons (138). Enrico Fermi experimented and believed the uranium nucleus absorbed a neutron and would become a heavier element (138). Irene stayed informed on experiments that Lise Meitner and Otto Hahn did in Berlin, but believed their results were incorrect (138). She and Savitch believed that the element that developed from uranium was

Lanthanum (138). Irene, like everyone else, assumed it could not be Lanthanum because it is lighter than uranium (138).

Irene published the results after repeating the experiment and finding what appeared to be Lanthanum a second time. Otto Hahn criticized Irene, saying, "She used her mother's old fashioned methods" (139). He also dubbed her newfound element a "curiosum" implying the Curies' were odd (139). Shortly after this, Hahn and Meitner tried Irene's experiment and came up with the same results (139). They also discovered barium, a substance lighter than uranium (139). Lise Meitner consulted her nephew, Otto Frisch, after realizing that uranium had broken into two pieces (139). Frisch named it fission, and Hahn received the Nobel Prize for the discovery (139). Irene read their report and exploded with, "Oh what dumb assholes we've been!" (139). She had been unable to figure out which rule of science her experiment contradicted (139). The Hahn team had Lise Meitner to figure it out (139). Irene and Fred always regretted not working together on this particular project (139).

Fred Joliot rushed to study fission and his team worked out an explanation of how a chain reaction would release a huge amount of energy (139). He could not conceive an atomic bomb being built in time to fight off Germany, so he focused on using the process of fission to supply France with nuclear energy (140). Today, thanks to Fred and Irene, 80% of France's power comes from nuclear power (140). After the fall of France,

Nazis' had requisitioned Irene's laboratory equipment, but returned it all by November 1940 (Byers, Moszkowski 4). Irene remained in the laboratory in

1940, while Fred was busy arranging the shipment of uranium to Great Britain and the United States for the atomic bomb program (McGrayne 140). Irene's tuberculosis worsened with the war time shortages of food and other necessities (140). She aged quickly and looked far older than her forties (140). She continued to work, and at one time became so exhausted she laid down on the floor and fell asleep (140).

Keeping up on the affairs of women in France, she applied to the Academy of Sciences every few years for membership (140). Fred was admitted in 1943, but she continued to be rejected by the Academy the rest of her life. (140). Every time Irene was denied, she would go public with a story of the Academy's discrimination against women (140). In 1911 the Academy voted to keep its all male status and this policy remained in force for four more decades (Hussey, Rand 3).

Fred's laboratory was taken over by the Germans in 1940, but they left his friend Wolfgang Gentner in charge (McGrayne 140). Gentner was anti-Nazi and together they planned out how to get the laboratory from advancing the Germans in the war (140). Fred had told them a ship had sunk with deuterium-enriched water when it was sailing for England (140). Fred joined the Resistance and became president of the biggest group in France (140). Fred was given the title of Commander of the Legion of Honor and awarded the Croix de Guerre (Marie 1).

The Gestapo killed many of the Joliet-Curies friends. Fred stated, "I became a communist because I am a patriot" (McGrayne 140). Being a communist had cost him his career in later years (140). Fred went underground with the resistance when Irene refused to leave France (141). She wanted to wait until her daughter received her bachelor's degree. Then in 1943, Irene was held with others when she fled the Nazis' trying to cross the Swiss border to Porrentruy (Hussey, Rand 3). She spent many days in a detention center and once they realized who she was, she refused any special treatment and insisted on remaining until everyone else was released (3). Irene finally fled with their children to Switzerland on June 6, 1944, which was D- day (McGrayne 141). They were lucky it was D- day, because the Germans usually kept border security very tight, but they were preoccupied (141).

At the end of the war, Marie's old friend, Missy Meloney, mailed streptomycin to Irene, ending her long battle with tuberculosis (141). She published a textbook in 1946, entitled, *Les Radioelements naturels: Proprietes chimique, preparation dosage* (Pycior, Slack and Abir-AM 65). She also wrote several papers on the roles of women in society, addressing such issues as equality in the workplace (67). She continued with her research, running the institute and attending meetings for women's rights and atomic bomb bans (McGrayne 141).

In 1948, she went to New York for a fundraiser for Republican Refugees from Franco's Spain, and was held by the United States Immigration in a cell on Ellis Island (142). McCarthyism and the red scares had a great impact on Irene and other scientists (Pycior, Slack and Abir-AM 70). The French authorities protested, and she was released in the morning (McGrayne 142). She told the press she had good accommodations and coffee (143). She denied being a communist and stated:

> I am not surprised to have been arrested and detained, because I am here to aid the anti-Fascists. And, in the United States, they prefer the Fascists and even the Nazis to the Communists. They think the first and second (the Fascists and the Nazis), have more respect for money (142).

She went on and concluded her tour and fundraiser successfully (142). In 1950, the French government fired Fred from his position at the French Atomic Energy Commission (142). The rest of their lives were spent working for peace (Marie 2). Irene's position was terminated after 1951 with the Commission (McGrayne 142). Sadly, they became ostracized all over the world. Author Sharon Bertsch McGrayne stated:

> When she later arrived in Stockholm for a physics conference, city hotels refused to give her a room. The British declined to give her a visa to attend a scientific conference. Despite her Nobel Prize, the American Chemical Society rejected her application for membership. Her Sunday afternoon open houses, attracted only a few friends (142).

Irene continued researching and experimenting. She even received government approval for a nuclear research center at Orsay, south of Paris (142). Fred developed radiation-induced hepatitis (142). She worked in the laboratory everyday until January 1956 (142). The next month she went to the Alps alone, turned severely ill and returned to the Radium Institute hospital (142). When she was diagnosed with leukemia she told Aline Perrin, her childhood friend, "I am not afraid of death. I have had such a thrilling life!" (McGrayne 142). She died on March 17, 1956 at the age of fifty-eight, and Fred died two years later (Hussey, Rand 3). Their daughter Helene became a physical scientist and their son Pierre became a biophysicist, carrying on the scientific dynasty (Pycior, Slack and Abir-AM 59).

The Joliot-Curie family: Irène Joliot-Curie, Frédéric Joliot-Curie, Hélène, and Pierre. Courtesy of Archives Curie et Joliot-Curie.

Pycior, Helena, Nancy G. Slack, and Pnina G. Abir-AM, eds. *Creative Couples in the Sciences*. New Brunswick, New Jersey: Rutgers University Press, 1996.

The Joliot-Curie family: Irène Joliot-Curie, Frédéric Joliot-Curie, Hélène, and Pierre. Courtesy of Archives Curie et Joliot-Curie.

Pycior, Helena, Nancy G. Slack, and Pnina G. Abir-AM, eds. *Creative Couples in the Sciences.* New Brunswick, New Jersey: Rutgers University Press, 1996.

The significance of studying the history and founders of radioactivity lies within our natural curiosity to know the origins of what we work with professionally on a daily basis. We have to be able to look at what our founders achieved; so we do not waste time making the same mistakes, and lack making improvements on existing necessary equipment. It is important for other scientists' to look back, so they do not lay claim to another's invention that existed many years prior. Michael Faraday was extremely careful when he was determined to prove a link between magnetism and electricity. Before he began any experiments on this subject he spent a whole summer researching what had already been done. He even titled his many notes, *A Historical Sketch of Electromagnetism,* which he published in three parts.

As a radiographer, one should have a basic knowledge and appreciation of the founders of our field and their inventions. We have to know how to utilize the equipment to our advantage in the work place, this requires more than knowing the fundamentals of physics. An example would be the "heel effect" of the x-ray tube. We utilize the cathode end of the tube for thicker, harder to penetrate parts of the body to create a better x-ray. We might ask where the terms cathode and anode come from? How do we know that the tube is more powerful at the cathode end? Faraday coined these terms and was one of the first to produce conductors, which formed sparks within vacuum tubes. Wilhelm Roentgen and Pierre Curie were careful not to publish their findings to soon, and often lost out on getting credit for their discoveries. Marie Curie, on Pierre's advice delayed publishing her findings on the activity of thorium and the credit went to German scientist, Carl Schmidt. From that day on Marie published as quickly as she could. Roentgen would never publish anything immediately, it was more important that his reputation as a scientist be one that exemplified systematic preciseness. Henri Becquerel came from a more privileged class where he was a third generation physicist. He was able to be more of a risk taker, and could afford to publish results quickly that would later prove to be false. His family name was held considerably high in France and having to retract false information would not affect his reputation. Likewise, Irene Curie although a talented physicist, was privileged because of her parents' discoveries. Unlike the others, Faraday was truly a poor man with very little formal education that worked his way up from bookbinder to acclaimed scientist. Faraday's other unusual characteristic was his ability to balance his love for science with his belief in god. Marie was raised poor but had an advantage because her parents' were very educated. Despite being under the role of the Russian Tsar, she managed to obtain a formal education. She actually graduated from the Sorbonne with two Masters degrees, one in Physics and one in Mathematics.

These individuals are an inspiration to anyone that desires working in a scientific field. Roentgen managed to discover the greatest invention of the 19th century, x-ray, at the age of fifty. Faraday overcame many obstacles to become a respected scientist, who made all his significant achievements at the age of forty. Oddly enough, without any formal education, he became known as one of the best teachers of science because of his Friday night lectures at the Royal Institution.

All of these scientists held the utmost ethics. They would deny any desire to compete or seek profit or patents on their work. In these early years, it was seen as unethical to seek money or fame. Their research and discoveries were purely to advance science and better society as a whole. Later, Marie Curie would change her position and serve on the

Intellectual Cooperation of the League of Nations; where she worked to secure the rights of scientists' to patent their discoveries. American scientists had already caught on to commercializing; but it was many years later that the European scientists changed their ethics regarding patents and profits. Marie was criticized for being a hypocrite because she pleaded poor, and received many gifts from the United States and France. She accumulated many properties and a nice size pension. She managed to pit France against the United States in their generosity toward her. France, not wanting to be out done, always gave in response to what the United States gave her.

Unfortunately, almost all of these pioneers of radiology began to notice its effects on their bodies. Roentgen was the exception, because he unknowingly protected himself from the radiation with the use of zinc-lined boxes and lead plates. Henri Becquerel suffered a severe radiation burn in his armpit after carrying a vial of radium. Pierre Curie and Becquerel published a paper of the adverse effects of radiation. Marie and Irene Curie ultimately died of blood disorders. Marie suffered severe radiation burns to her hands, and died of anemia, now thought to have really been leukemia. Irene and her husband Frederic had often mouth pipetted radioactive materials. Fred died from radiation-induced hepatitis and Irene died of leukemia. Marie along with Antoine Bedere and Claudius Regaud, recommended regulations for radiation protection and submitted them to the Minister of Work and Health (Quinn 413).

When x-ray was first discovered laws and regulations were put into place regarding its use. There was so much concern that a London Company manufactured protective underwear. There was also a considerable amount of quackery, and opportunists used the Curies' name (387). They sold hair tonics that promised eternal youth (410). In 1929, there were radioactive ingredients in the form of candy, liniment, toothpaste and bath salts (410). One of the most shocking applications of radioactive treatments came with the onset of World War I. Soldiers were injected intravenously with radium solutions in cases of blood loss, and they used applications of radon and radium to soften scar tissue and loosen joints (410).

These scientists formed a chain of events that changed our lives and understanding of our bodies forever. It begins with Faraday in 1838, when he discovered conductors. He wanted to observe the sparks of activity and created a vacuum in a tube. He also coined the terms cathode and anode within the tube. Crookes improved upon the vacuum tubes,

and, later Roentgen discovered x-rays in 1895. Faraday also found that electricity could be produced from a magnet. This became the basis for the modern day magnetic resonance imaging. He noted that the magnetic field had to be pulsed in order for it to be sustained.

Roentgen's discovery of x-rays was the most important invention of the 19th century. He happened upon x-rays just by chance while evacuating a tube, and inadvertently exposing a plate coated with plantinocynide. Then in 1896, Antoine Henri Becquerel inspired by Roentgen's rays began to study phosphorescence. He inherited uranium salts from his father and began experimenting by taping them to photographic plates. He wanted to expose them with sunshine, thinking they absorbed the rays. However. France had more than one cloudy day, and he ended up storing them in a drawer. Like Roentgen, by chance he developed them not expecting any exposure, and found them exposed. He had discovered natural radiation from uranium.

Marie Curie had been Becquerel's graduate student and needed a topic for her doctorate thesis. She found uranium rays to be an interesting subject, because very few people were researching them. While researching uranium, Marie and Pierre discovered two other radioactive materials, polonium and radium in 1898. It took four years for Marie to isolate radium from refined uranium. They shared a Nobel Prize with Henri Becquerel in 1903. Marie won a second Nobel Prize for isolating metallic radium in 1911. The Curies' daughter Irene and her husband won a Nobel Prize in 1935 for their discovery of artificial radioactivity in 1934. This led to nuclear energy, and the creation of the atomic bomb in 1945.

With the onset of World War II, the United States dropped the atomic bomb on Hiroshima, Japan. Three days later, they attacked Nagasaki, Japan with a second bomb. . Many people that managed to survive were severely burnt and scarred. The bombs continued to kill thousands of people in Japan years later because of radiation- induced cancer. The levels of diagnostic radiation we use today are a small fraction of what Marie and her lab workers were exposed to on a daily basis. World War II changed the publics' opinion of radiation from hopeful to fearful. Diagnostic radiology and radiation therapy are areas of medicine in which each patient has to be individually evaluated in terms of fears and phobias of radiation. The technologist must make use of their historical knowledge of radioactivity to allay unnecessary fears of patients'. Clinical training alone cannot totally offer the training needed. Patients often wonder if the machines are old, or if they are getting an excess of radiation. They have a natural curiosity about the origins of radiation, and how it reacts. The general public is not aware that regulations on x-ray have been enforce for many years, or that physicists check the equipment once a year. They do not realize the walls of the x-ray room are lined with lead in order to repel the rays. Technologists' have a responsibility to inform patients about radiation; utilizing their knowledge of the founders of radioactivity combined with clinical expertise.

Many people do not realize that radiologic technologists are required to have formal training and certification. Training for the profession may be offered in universities and colleges, hospitals, vocational-technical institutes and the army.

Preparing for the profession generally requires a two-year program. Programs range from one to four years and award a certificate, associate's degree or bachelor's degree.

The Committee on Allied Health Education and Accreditation accredits most of the formal training programs. The Consumer-Patient Radiation Health and Safety Act of 1981 protects the general public from unnecessary exposure to radiation by making sure technologists are properly trained. This act makes sure the States abide by standards set by the federal government when accrediting training programs for radiologic technologists. Most states require registered technologists. The American Registry of Radiologic Technology registers technologists that are graduates of an accredited program and have passed a registry examination.

Works Cited

Badash, Lawrence. *Becquerel, (Antoine-) Henri.* 1979 Encyclopaedia, Inc. 8 November 2002<http://www.elmhurst.edu:8081/nobel/micro/5913.html>.

Biography-Henri Becquerel. 2002. The Nobel Prize Foundation. 24 September 2002<http://www.nobel.se/physics/laureates/1903/becquerel-bio.html>.

Biography-Irene Joliot-Curie. 2002. The Nobel Prize Foundation. 15 March 2002<http://www.nobel.se/chemisty/laureates/1935/joliot-curie-bio.html>.

Biography-Wilhelm Rontgen. 2002. The Nobel Prize Foundation. 16 June 2000 <http://www.nobel.se/physics/laureates/1901/index.html>.

Broca, Andre. "The Work of Henri Becquerel." *Smithsonian* 30 October 1908:769-785.

Byers, N., and S.A.M. Moszkowski, eds. *Irene Joliot-Curie 1897-1956.* 1996 CWP and Regents of the University of California. 4 September 2002 <http://www.physics.ucla.edu/~cwp/Phase 2/Joliot-Curie,_Irene841891460..html>.

Cantor, Geoffrey., David Gooding, and Frank A.J.L. James. *Michael Faraday.* Amherst, New York: Humanity Books, 1991.

Curie, Eve. *Madame Curie.* New York, N.Y.: DaCapo Press, 1986.

Glasser, Otto. *Dr. W.C. Rontgen.* Springfield Illinois: Charles C. Thomas Publication 1945.

Greene, Jay E., ed. *100 Great Scientists.* New York, N.Y.: Simon and Schuster, Inc., 1969.

Grey, Vivian. *Roentgen's Revolution: The Discovery of The X-ray.* Boston: Little, Brown and Company Publications, 1973.

Gunston, David. *Michael Faraday, Father of Modern Electricity.* London: Weidenfeld and Nicolson Ltd, 1962.

Hallock, Grace T. *Health Heroes-Marie Curie.* New York, N.Y.: Metropolitan Life Insurance Company Press, 1937.

Hussey, George, and Ruth Rand. *Irene Joliet-Curie.* Woodrow Wilson Leadership Program in Chemistry. 29 August 2002<http://www.woodrow.org/teachers/chemistry/institutes/1992/Irene Joliot-Curie.html>.

Marie Curie and the Science of Radioactivity. 26 December 2001 American Institute of Physics.<http://www.aip.org>.

May, Charles Paul. *Michael Faraday and the Electric Dynamo.* New York: Franklin Watts Inc., 1961.

McGrayne, Sharon Bertsch. *Nobel Prize Women in Science: Their Lives, Struggles and Momentous Discoveries.* Washington, D.C.: Joseph Henry Press, 2001.

McMurray, Emily J., Jane Kelly Kosek and Roger M. Valade III, eds. *Notable Twentieth-Century Scientists.* Detroit, MI: Gate Research, 1995.

Michael Faraday 1791-1867. 2001. The Institution of Electrical Engineers. <http://www.iee. org./The/IEE/Research/Archives/faraday/.cfm>.

Nobel Prize Pioneer at the Pantheon-Marie Curie. 8/1995 Label France. 26 December 2001>http://www.france.diplomatic.fr/label_france/ENGLISH/SCIENCES/CURIE/marie>.

Pycior, Helena, Nancy G. Slack, and Pnina G. Abir-AM, eds. *Creative Couples in the Sciences.* New Brunswick, New Jersey: Rutgers University Press, 1996.

Quinn, Susan. *Marie Curie: A Life.* New York, N.Y.: Simon and Schuster, 1995.

Romer, Alfred, ed. *The Discovery of Radioactivity and Transmutation.* New York, N.Y.: Dover Publications Inc., 1964.

Thomas, John Merurig. *Michael Faraday and the Royal Institution.* London: Institute of Physics Publishing, 1991.

Woodard, Peggy, and Roger Freimarch, eds. *MRI for Technologists.* New York, N.Y.: McGraw-Hill Inc., 1995.

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